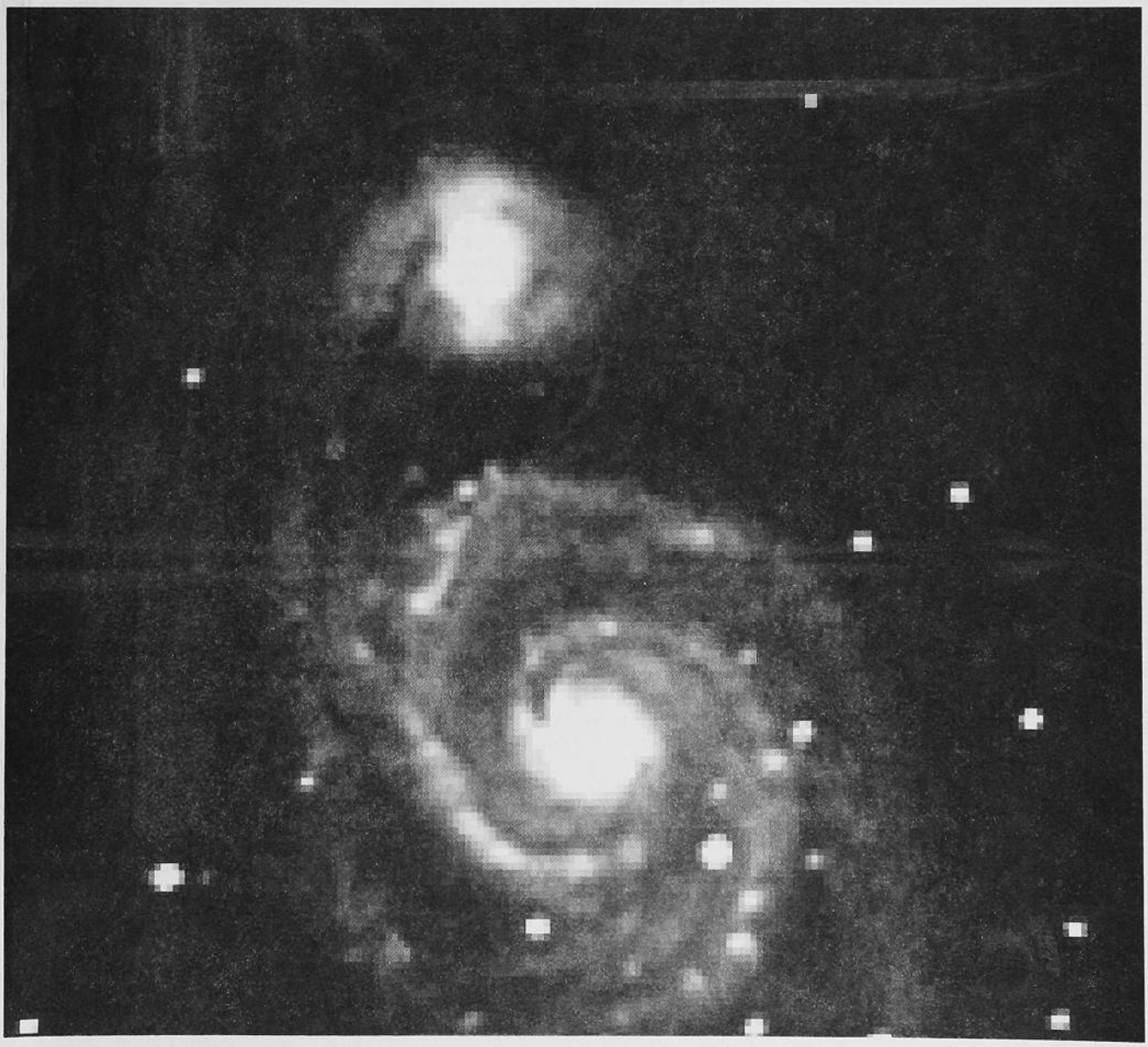
TELESCOPE MAKING 41

ISSN 0190-5570

The magazine *for*, *by*, and *about* telescope makers! **Summer 1990**



Telescope Making #41

The magazine *for*, *by*, and *about* telescope makers!

Editor: Richard Berry
Associate Editor: Peter Ceravolo

TELESCOPE MAKING (ISSN 0190-5570) is published quarterly by Kalmbach Publishing Co., 21027 Crossroads Circle, Box 1612, Waukesha, WI 53187. Copyright ©1990 by Kalmbach Publishing Co., all rights reserved. Material in this publication may not be reproduced in any form without written permission. Second-class postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to TELESCOPE MAKING, 21027 Crossroads Circle, Box 1612, Waukesha, WI 53187. Direct subscription questions to (800) 446-5489. Direct editorial submissions to the address above, telephone (414) 796-8776. The opinions expressed in this magazine are not necessarily those of the publishers or editors. Not responsible for unsolicited materials. Names and address of authors will be printed unless specifically requested otherwise. Subscription price (U.S.): one year $12; single issues $3; foreign: one year $14; single issues $3.50. Clubs and dealers: Inquire about bulk rates. Editorial Secretary: Tracy Staedter; Art Assistant: Patti Keipe; Advertising: Greg Swan/Dana-Lynne Terry. Printed by Port Publications, Port Washington, WI.

In this issue...

2 **Editorial**

3 **Letters**

4 **A Simple Unobstructed Telescope**
by David Shafer

8 **An Observing Ladder for Big Telescopes**
by David Kriege

12 **The Nuances of Optical Testing**
by Peter Ceravolo

20 **A Breakdown Telescope for Club Use**
by Bob Drew

26 **How to Paint an Observatory Dome**
by Barry Beaman

28 **Riverside 1990**
by Richard Berry and Peter Ceravolo

46 **Blue Pages Classified Advertising**

Cover: A Patterson SS700-series CCD camera shown at this year's RTMC captured this image of the Whirlpool Galaxy in a two-minute exposure on a C8 telescope. To create the cover, a small section was clipped from the original, the image data was log rescaled for a long tone scale and unsharp-masked to accentuate fine detail, and pasted into place with DTP software. Digital image data courtesy of Burt Patterson and Tom Quinn of Patterson Electronics.

Editorial

Who would have guessed it? Spherical aberration made the front page of the New York Times and appeared on the evening news on a thousand TV stations around the world, stirring the anger and consternation of liberal and conservative pundits alike. For the lack of an optical test, the Hubble Space Telescope, the pride of America's space program, became a national embarrassment.

The public heard that a telescope with defective optics couldn't do what a telescope should do. The carefully weighted assessments of how much "science" remained doable in the presence of several waves of spherical aberration sounded lame not because the ultraviolet spectroscopy is unimportant, but because the Hubble Space Telescope was advertised to do much more.

Those claims that testing would have raised the cost of Hubble seem weak indeed. What is the cost to public confidence in astronomers? How will the public and the Congress regard funding programs like the Space Telescope in the future? What value can we place on the loss of interest in astronomy among a public that scorns fools and losers?

The questions that *Telescope Making* has raised about the quality of commercial optics seem all the more relevant in light of Hubble's troubles. All astronomical telescopes, whether low-cost Dobsonians, Schmidt-Cassegrains, or a Hubble Space Telescope, are sold with the implicit promise that the optical system will deliver diffraction-limited images. Any telescope that fails to deliver this *sine qua non* is a telescope that doesn't do the job

the buyer bought and paid for.

In the commercial realm today, things are looking up. In April, at the invitation of Ira Herman at Meade and Alan Hale at Celestron, I spent two days talking turkey with the people at Meade and another two days with Celestron. The visit confirmed my worst fears that quality had become a secondary consideration in the tough years following the Halley apparition.

However, I am pleased to report that the situation has improved greatly over what it was. Today both companies are dead serious about quality, and not just optical quality but mechanical and electronic performance, too. Meade's comprehensive quality program, for example, puts every telescope through a battery of tests before it leaves the factory, including a 24-hour burn-in for the electronics, a critical optical test on an artificial star, and a 49-point mechanical check. Two SCTs that I saw in Meade's optical assembly room would satisfy my needs as an observer.

On the optics-only front, Galaxy is building a solid reputation for quality at a reasonable price. I've had the opportunity to star test six of their mirrors, and all were good or very good. Several other makers are likewise building good reputations, but I haven't seen more than one or two of their products, so it's not fair to judge or comment at this time.

It gives me great pleasure to report these observations to the *Telescope Making* readership. Because the industry is dealing with its quality problem, both manufacturer and buyer will benefit.

—Richard Berry

Letters

Oops! Again—and Apologies

Dear Richard/ In *TM#40* you printed my letter in which I attempted to correct the numerical labels of Figures 10 and 11 in our Ross Null Test article in *TM#39*. Unfortunately typographical errors were made in the printing of *TM#40*, and the values I had given to you were printed with the decimal points left out (+100 and -100 should read +0.100 and -0.100; +400 and -600 should be +0.400 and -0.600). Alert readers could have probably caught the printing errors, however, as I did mention that the correct numbers were 50 times larger than the original numbers in *TM#39*.

I would like to thank all those readers who have responded with inquiries about the Ross Null Test. Peter and I have enjoyed the opportunity to make the technical details of the Ross Null test available to TMs for their use. The article presents the results of hundreds of hours of calculation and compilation, thus saving hundreds of other TMs the agony of doing the same thing as we had to do.

David E. Stoltzmann
368 North Ninth Street
Bayport, MN 55003

—My apologies for the error in the correction; we used a scanner to "capture" your letter, and the scanner missed the decimals. Because of its obvious benefits, I believe that the Ross Null will gain a substantial following among amateur telescope makers. —RLB

continued on page 44...

Editorial

The product reviews that have appeared in ASTRONOMY and *Sky and Telescope*, as well as the numerous letters from readers of *Telescope Making* complaining of poor optics in commercial instruments, have exposed a deep dissatisfaction that has been growing for years.

There will always be a need for inexpensive telescopes and optical components of reasonable quality. Unfortunately some manufacturers have offered low-priced optics but failed to deliver advertised quality on a consistent basis. This practice makes it difficult for the individual who wants the best optics for a given amount of money, and it is unfair and illegal competition for those manufacturers who advertise and consistently deliver high quality but must charge more to cover the increased cost of manufacture. In the best interests of amateur astronomy, we need a level playing field through fair and honest advertising.

After testing many telescopes for the last three years and considering the findings of other people, I must conclude reluctantly that the problems I have seen with optical quality in some commercial instruments and components have not been isolated incidents. This has no doubt caused some amateur astronomers to eye commercial optics with some suspicion. Many amateurs who formerly bought on trust now go to the trouble of testing their optics in the field or on an optical bench.

But optical testing is hardly a straightforward process. Testing is fraught with subtleties and difficulties that mislead the novice and sometimes the advanced practitioner into

thinking that an otherwise good optical system is of poor quality. In order to save the amateur astronomer and telescope manufacturers a lot of trouble, Richard and I thought that some of the problems associated with optical testing should be addressed immediately. We hope "The Nuances of Optical Testing" in this issue of *Telescope Making* will help you avoid the pitfalls of telescope testing.

I have been a reader of *Telescope Making* from its inception. I am now privileged to be a small part of the team that brings you each issue. The work of my predecessor, the late Bob Cox, is a tough act to follow. I often refer to several thick binders of reference articles on all aspects of telescopes and optics from Bob's *Sky and Telescope* days and, of course, his contributions to *Telescope Making*. It is because of Bob's lifelong commitment that the hobby of telescope making is alive and well today .

Peter Ceravolo
P.O. Box 27092
Gloucester, Ontario
K1J 9L9
Canada

A Simple Unobstructed Telescope with High Performance

Introduction The ideal optical system for a telescope would be highly corrected for all aberrations, unobstructed, simple to make, and require no aspherics or expensive glass types. The known types of unobscured telescopes that do not involve aspherics, such as refractors and tilted component designs, achieve high performance only by going to very slow focal ratios with long tubes. Conventional refractors are limited by secondary color, and apochromats require expensive exotic glasses.

Aspherics permit faster speeds and higher performance but require surfaces that are difficult to make and test. What is needed is an unobstructed design that works at speeds like f/8, uses the most common and least expensive glass type, has no color over the visible spectral range, is diffraction-limited over a wide field of view, and has only a few spherical surfaces.

New Design Figure 1 shows just such a new type of telescope. Design data are included here for a 6-inch aperture f/8 system. The two front lenses are made of Schott BK-7, the most common kind of optical glass. The design can be redone to use any available glass, however. The primary mirror is spherical. The design has no detectable color throughout the visible spectrum, including the very deep blue.

Performance is diffraction-limited over a field of view 2 degrees in diameter on a very weakly curved image surface, and 1.5 degrees in diameter on a flat but tilted image plane. If the design is scaled up to a 10-inch aperture f/8 design without being reoptimized, the diffraction-limited image plane is still 1.25 degrees in diameter.

The theory behind this new tilted-component design is similar to the theory behind Schiefspieglers, which explains why it has such high performance with such weak curves. This design is much faster in speed than a Schiefspiegler, however, and considerably shorter when compared to its focal length.

The tube layout is exactly like a conventional Newtonian except that the diagonal mirror is off to one side of the tube. The design is thus unobstructed. The tube length is about the same as for a conventional f/8 Newtonian.

The size of the spherical primary mirror is up to you. If it is sized to catch the complete 2 degree field of view, with no vignetting, then it should be about 7.5 inches in diameter for a 6-inch clear aperture. Vignetting would not be especially noticeable even if the primary mirror were made as slittle as 6 inches in diameter.

The image surface is tilted by about 6 degrees with respect to the incoming light. If the eyepiece is oriented so its axis is parallel to the direction of the incoming light, then the tilted image will not be equally in focus.

This should not be especially objectionable, and can be eliminated by using the eyepiece with its axis perpendicular to the image surface. For photography the camera would have to be tilted to ensure that the image is in focus over the whole 35mm film format.

The center of the optimum field of view makes an angle of about 0.35 degrees relative to the optical axis of the front lens. A diagonal flat mirror can be fit in near the image.

The second lens (surfaces #3 and #4) is tilted about its vertex by 5.38 degrees relative to the front lens. The mirror, surface #5, is tilted about its vertex by 3.0 degrees relative to the front lens. The image is tilted roughly 6 degrees to the center of the incoming f/8 beam.

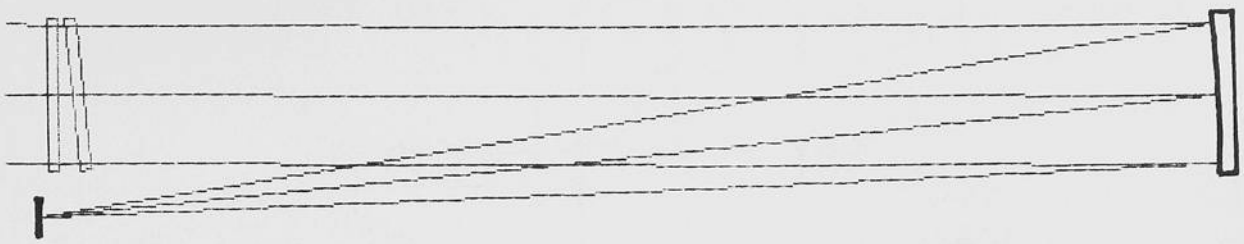
Tolerances The two non-flat lens radii (surfaces #1 and #4) have equal and opposite curves, and the mirror radii each have a tolerance of ±0.5 inch. The lens thickness tolerance is ±0.05 inch. The lens-to-lens spacing tolerance is ±0.10 inch, while the spacing between the lens and mirror is ±0.5 inch.

The lenses are Schott BK-7, or any equivalent. The design can work with just about any glass type if the lens radii are changed.

Making It I have not yet made this design. The tolerances are all quite loose, with one exception. Once the tilt of the second lens has been set, with respect to the first lens, the tilt of the primary mirror must be chosen quite carefully.

I suggest setting the tilt of the second lens by measuring the difference in edge separation between the opposite sides of the two lenses. It should be easy to set this tilt angle within 0.1 degree or so of the correct value by this method. Then the primary mirror can be tilted while observing a star to tune up the performance.

David Shafer
56 Drake Lane
Fairfield, CT 06430



Unobstructed 6-inch f/8 Corrector-Herschelian

Editor's Note: This latest Shafer design is essentially a catadioptric Herschelian telescope and is corrected to about 1/4-wave r.m.s. A similar design using a sub-aperture corrector was published by Richard Buchroeder in the January 1971 *S&T*. Although lens work should never be approached lightly—and shouldn't be approached at all unless you have made several good mirrors—this design is well suited to the basement optician.

The large corrector lenses are easily made by hand. Small correctors, although less expensive in terms of glass cost, are harder to handle when working by hand without the aid of a motorized spindle. Lens making requires more tools than mirror making because the radii have to be carefully controlled, usually with a spherometer, and the difference in thickness at the edge must be minimized (dewedging) with the aid of a special jig and a micrometer or dial indicator (see *TM#3*, page 40).

The radii of the Shafer design are not as steep as those of the average refractor and the tolerances are quite loose, so a spherometer is not required. The curved lens surfaces can be worked together, and the careful worker should be able to get the radii within 1/8 inch of optimum. The radius of the concave surface of the lens can be checked during fine grinding with a flashlight and a cardboard mask, working as follows.

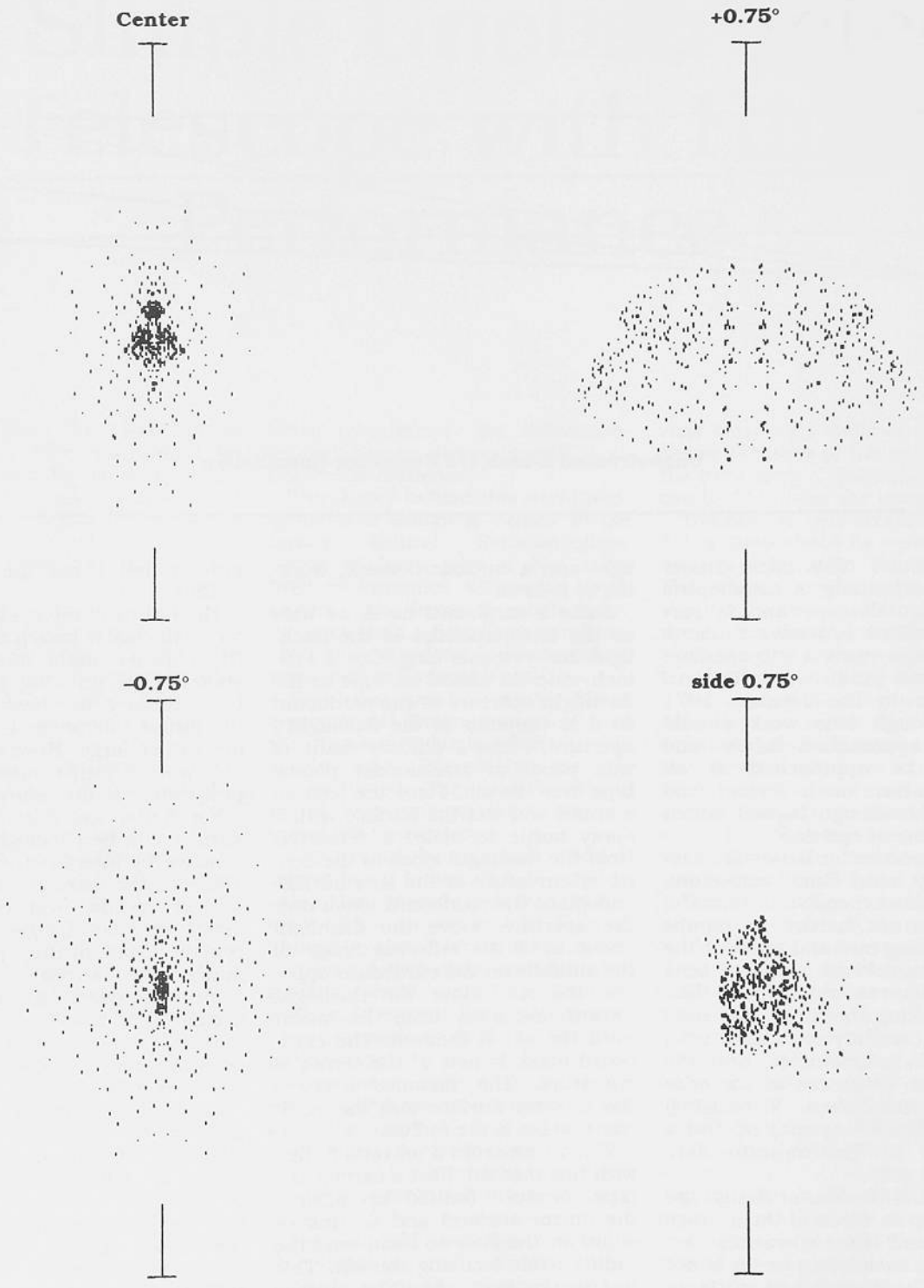
Make a cardboard mask as wide as the front aperture of the flashlight and twice as long. Cut a 1/8-inch-wide slit almost as wide as the flashlight aperture in the cardboard so it is centered in the flashlight's aperture. Place a diffuser made of wax paper or translucent plastic tape over the slit. Place the lens on a stand and wet the surface with a spray bottle to make it reflective. Hold the flashlight close to the center of curvature of the lens surface and place the cardboard mask over the aperture. Move the flashlight about until the reflected image of the slit falls on the cardboard opposite the slit. Move the flashlight toward and away from the mirror until the slit is focused. The cardboard mask is now at the center of curvature. The distance between the concave surface and the cardboard mask is the radius.

When I measure a mirror's radius with this method, I set a carpenter's tape measure (butted up against the mirror surface) and the mirror stand on the floor so I can read the radius while focusing the slit. This test works best when the surface has been ground with #220 and finer grits because a clearer image of the slit is formed by a fine surface. For greater accuracy, you can buff the fine-ground surface with a pitch tool and Foucault test it. Be sure to hot press the tool before buffing.

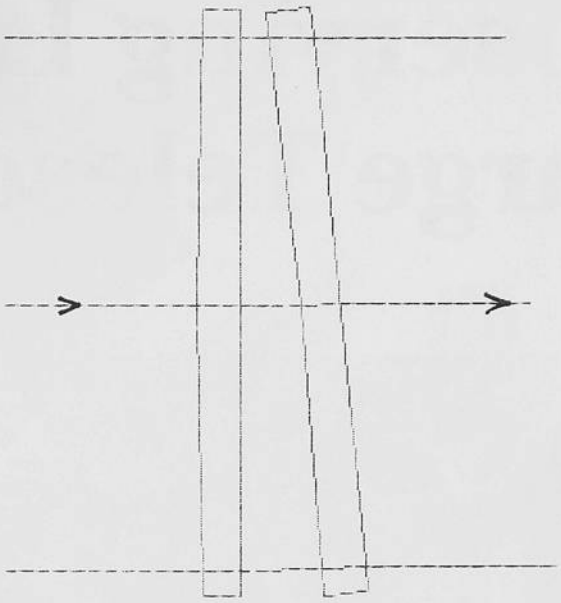
The radius of the convex lens surface will closely match the radius of the concave mate after the final stages of fine grinding. It should not be necessary to check it because the radius tolerances in this design are rather large. However, this will only work if your concave surface is pretty close to the desired radius.

For better accuracy, the convex surface can be checked against the concave by interference (see *TM#3*). The convex surface will have a shorter radius, and you will see many circular fringes. Work the center down during polishing to match the surfaces, but don't neglect the edge. After the surfaces match to a few fringes, alternate tool and lens on top to spread the polishing action to the edge without shortening the radius.

Making flat surfaces can be a problem for the telescope maker. The lens blanks purchased from Schott or United Lens will probably be diamond machined accurately flat. To maintain this flatness, flip the lenses around regularly while grinding and check the surfaces with the straightest edge you can find. A new machinist's steel rule is helpful in detecting gross errors. The diamond ground surface is smooth enough to start with #320 or #400 grit. It is best to work the flat surfaces first, removing only



Ray-trace Analysis: Shafer 6-inch f/8
(courtesy of Dick Buchroeder)



Corrector Lenses: Convex/plano and Concave/plano

Design Data for 6-Inch f/8 Tilted-Component Houghton Camera

(all dimensions in inches)

Surf	Radius	Thick	Glass
#1	81.60	0.45	BK7
#2	Flat	0.65	air
#3	-81.60	0.40	BK7
#4	Flat	46.00	air
#5	-96.00	-47.83	Mirror (sphere)
#6	Image		

enough material to grind out pits, since the wedge and center thickness can be controlled while working the curved surfaces.

Flatness is best checked by interference. The problem is most TMs don't have a master flat to check their work against. However, the absolute flatness of the surfaces can be gauged against a readily available Newtonian diagonal that has had its aluminum coating stripped. (See *TM#39*, page 22 for instructions on stripping aluminum. I use readily available—from the supermarket—sodium hydroxide or lye to strip nonovercoated mirrors.) Most inexpensive diagonals will be flat to within two waves (four fringes), which is sufficient for this design. Use the largest possible flat for this test.

Use several layers of heavy plastic tape to protect from damage the surface of the lens that you are making. Cut a small square from the tape at the center of the lens so you can check thickness. Also cut at least six notches in the tape at the edge for wedge testing.

When you polish the lenses, press the lap and lens surface often. This helps to achieve the smooth surfaces that are so important for good images. Do not use the mating curved surface as a base for the pitch polisher. It is wiser to cast a plaster tool (sealed with shellac or resin) for the polisher.

The BK7 glass for this design can be ordered from Schott Optical Glass at 400 York Avenue, Duryea, PA 18642, Attention: David Conn. It is best to phone David at Schott, (717) 457-7485. Tell him you're a TM. I have talked to David, and he is prepared to help TMs. Ask for a quote over the phone, then send a money order with your order through the mail. The glass will cost about $100.

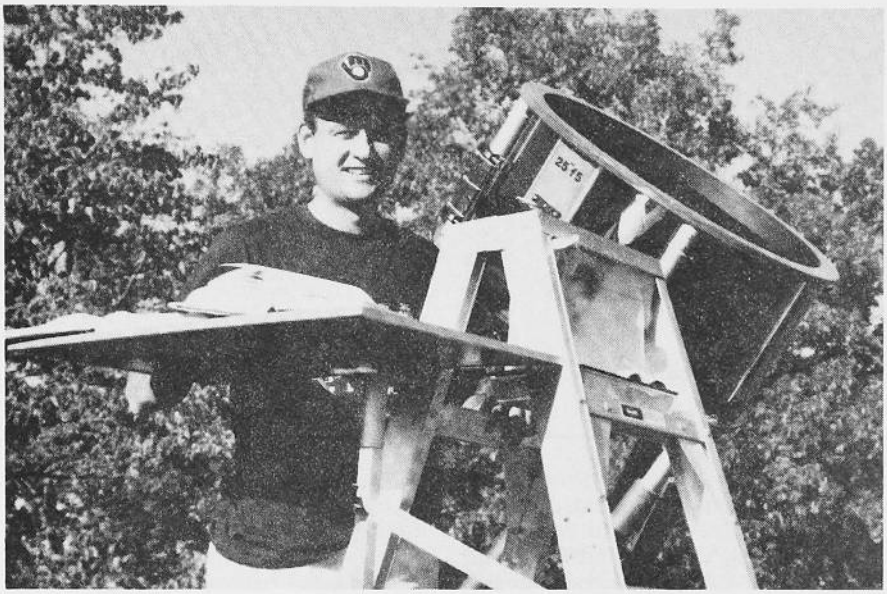
Order the glass blanks about 0.25 inches oversize for mounting purposes and to minimize the effects of the dreaded turned down edge. Add 0.05 inches to the nominal lens thickness plus tolerance for stock removal during grinding. The lens blanks should be 6.25 inches in diameter and 0.55 inches and 0.50 inches thick for the convex and concave lenses, respectively.

TMs may also wish to inquire about the lens blanks from Newport Glass Works (see their ad in *TM#40*, page 46). Optical glass as well as Pyrex can be purchased from United Lens Company of Southbridge, MA 01550, (508) 765-5421.

For all new designs, we recommend the builder run a ray trace. I asked Dick Buchroeder to look at this design and run a raytrace for *Telescope Making*'s readers. He notes that the design is "remarkable for being able to cover a field of 1° to 2° without a central obstruction," and that it is diffraction limited over about 1.5°. He comments, however, that chromatic aberration is not insignificant in this design. Dick also felt that tipping the positive lens might reduce that color.

—Peter Ceravolo

An Observing Ladder for Large Telescopes



Standing six feet off the ground on a shaky ladder makes for precarious observing. Yet as telescopes get larger, it's more and more common. After finishing Obsession 2, my 25-inch f/5 Dobsonian (see *TM#37*), it didn't take me long to realize that I would need a better ladder than my old six-foot household ladder if deep-sky observing was going to remain any fun.

My custom observing ladder is a well-built professional aluminum eight-footer made by White Metal, Inc. I paid $175.00 for it, and it's worth every penny. It has steps running up both sides, which not only make the unit stronger, but allow two people to stand on the ladder at once. This works out great during star parties. I can be at the eyepiece with the observer and can recenter the image and tell them what they are looking at.

With the new ladder it's lots of fun watching an eight-year-old kid climb up for a look at M13. His or her heart is already racing by the time he or she gets up to the eyepiece. Many people need a long time to get adjusted to the telescope, learn how to focus, and get used to the eyepiece or the limitations of their eyeglasses. When I'm there, just on the other side of the ladder, I can coach them better.

I chose an eight-foot ladder because, although a six-foot ladder might be tall enough, I wanted it to be safe and solid. The extra two feet are not to stand on; instead they give me something solid to cling to. Because I am six feet tall, I never have to climb more than four steps to reach the eyepiece at the zenith. The extra height also helps me keep my balance. With my right elbow resting on an upper step, moving the telescope with my left arm is a cinch.

In addition, taller ladders have a wider base, making for the stability, necessary during setup and takedown of the cage assembly. Falling off an insufficient ladder or dropping the cage would make for a spectacularly bad way to end an observing evening.

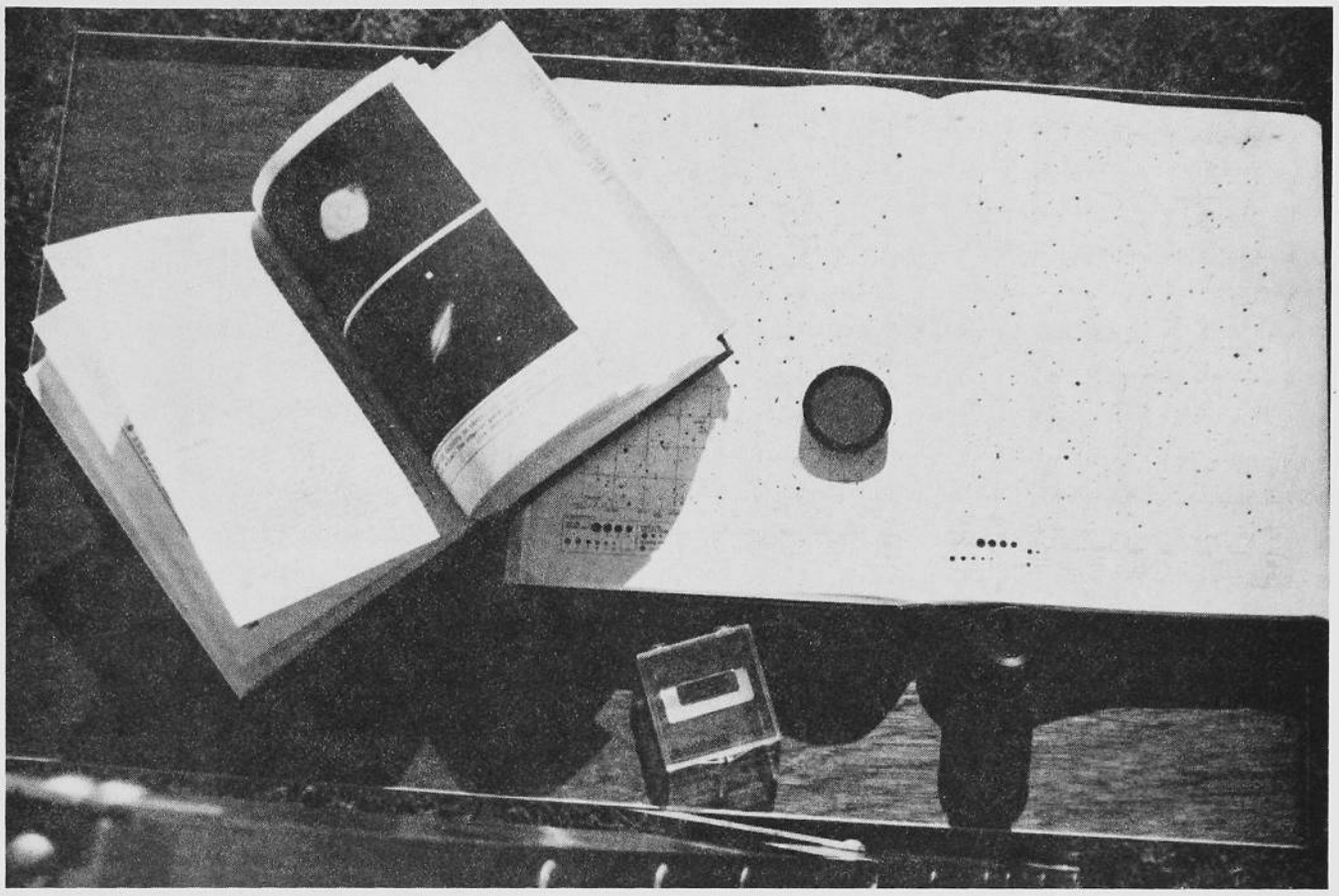
My first modification to this ladder was to place cheap 7-inch-diameter plastic lawn mower wheels on all four legs. These wheels really help positioning. I also added two lightweight chains across the base as insurance against a catastrophic collapse should a rivot pop out of a spreader arm. I was surprised to find how much the chains increased the stability, and they also eliminate much of the creaking and groaning common to aluminum ladders.

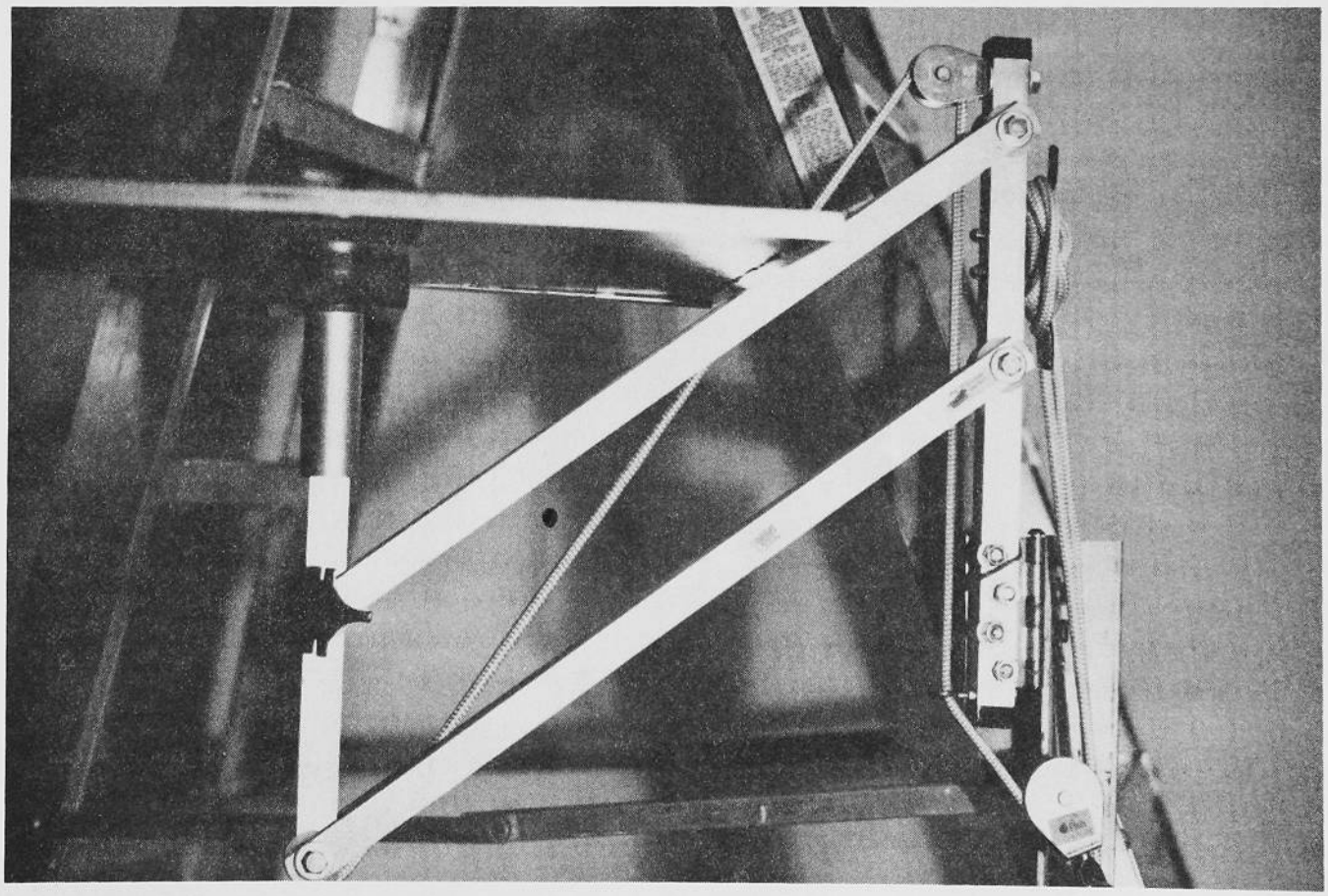
For me, sensitivity to faint objects is directly related to my personal comfort. Stretching or crouching my body to get my eyeball into position is not only a pain but also means I can see less. To end the stretching, I added two Baltic birch plywood steps between the stock steps. Of all the additions I made to this ladder, the two extra steps have helped me the most.

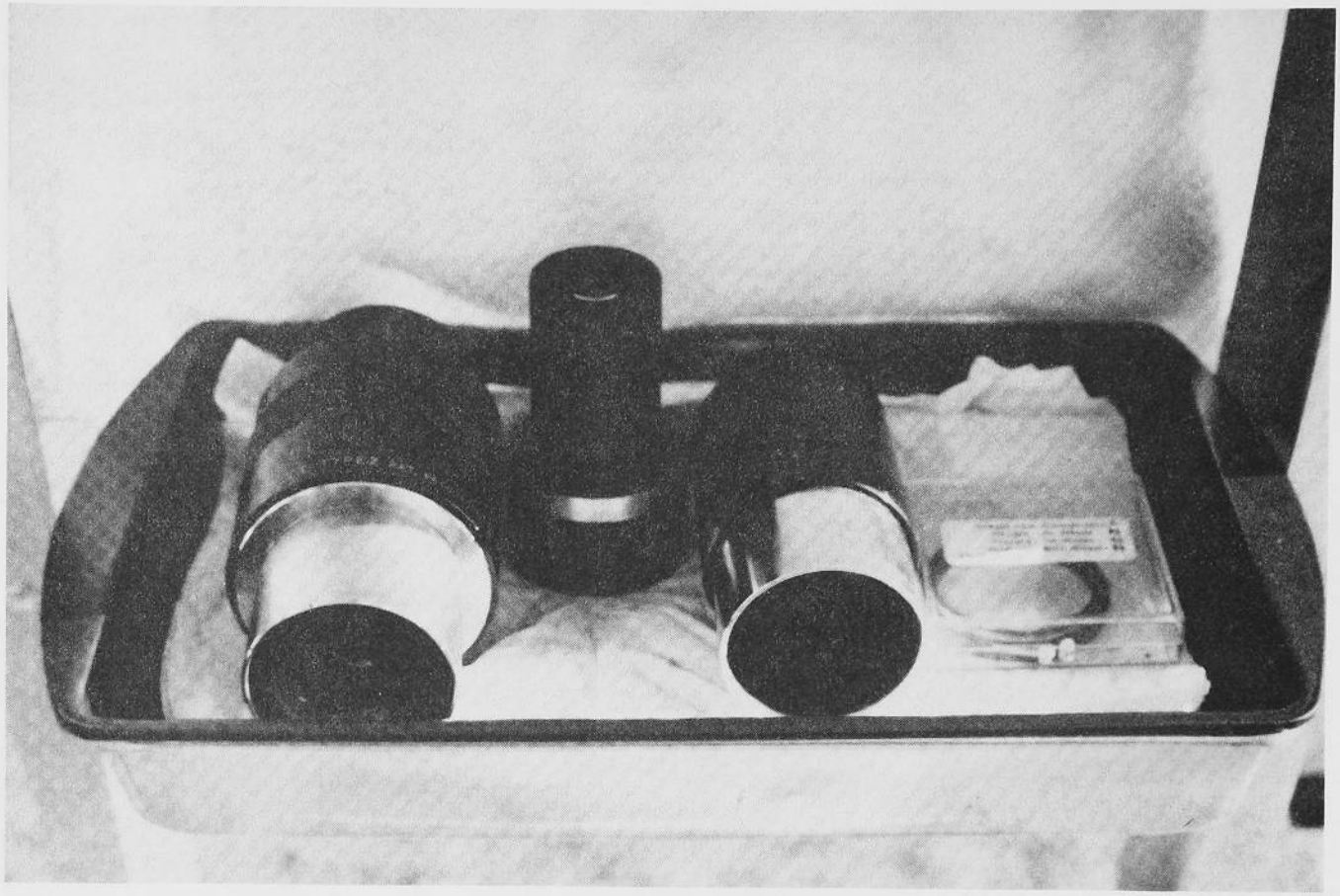
With a solid foundation beneath me, I soon found myself annoyed with chasing up and down the ladder. Need a light pollution filter? It's down the ladder, then back up, again! Want to consult an atlas? Either balance it wide-open on a step or—well, you get the idea. What I needed was a way to get my eyepiece, filters, a small tape recorder, atlases, and myself all together up at the focuser.

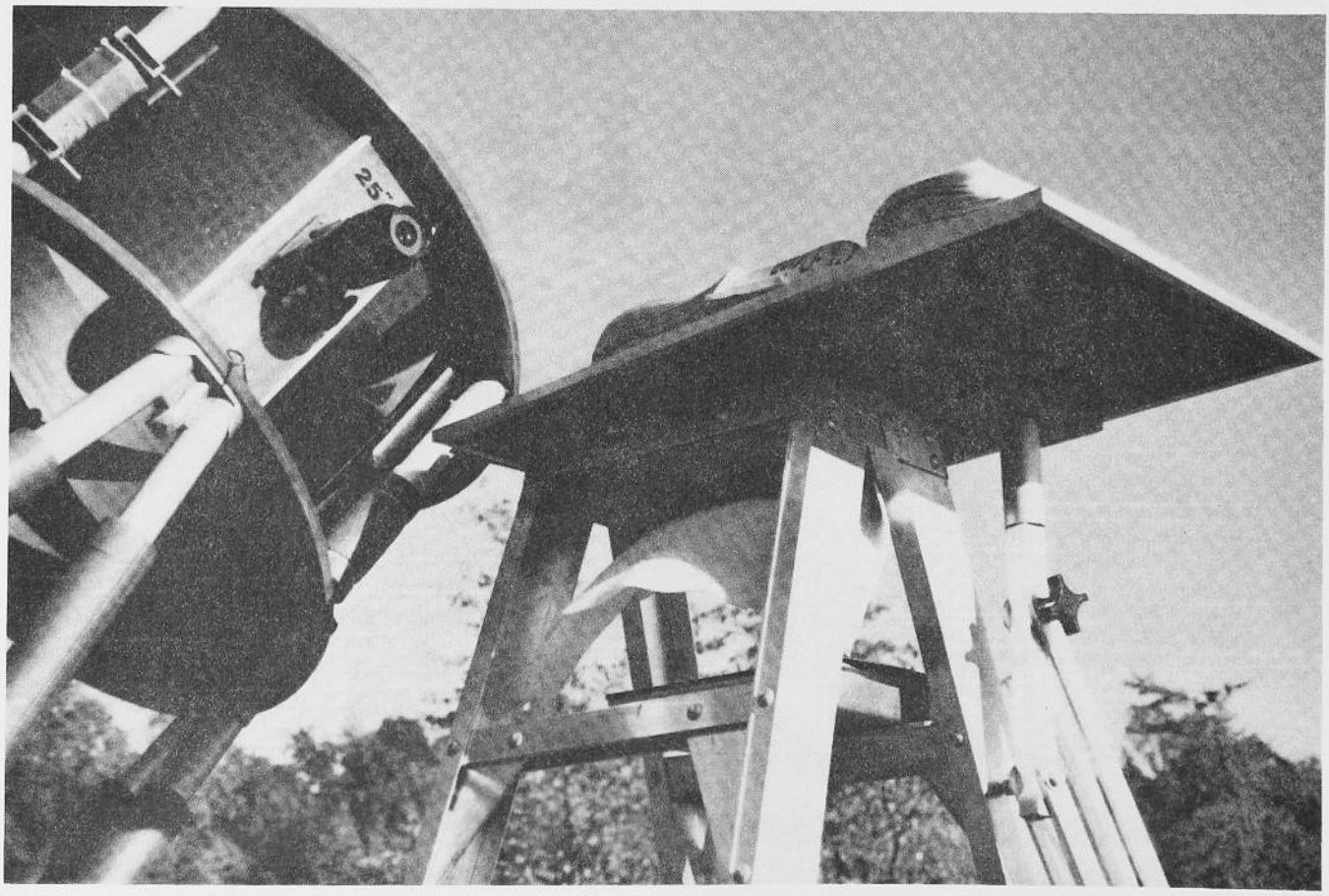
To answer this dilemma, I borrowed from my experience as a dentist. In dentistry, efficiency is extremely important. No patient has ever gotten up out of my chair and complained that I worked too fast.

Imagine having your books and charts within easy reach while youy observe from a ladder—well, that's what the parallelogram table does!









The way we dentists do it is by having everything we need at our fingertips. Similarly, everything I need except my printed materials is placed in a felt-lined 7x11-inch aluminum cake pan similar to my dental instrument tray setups.

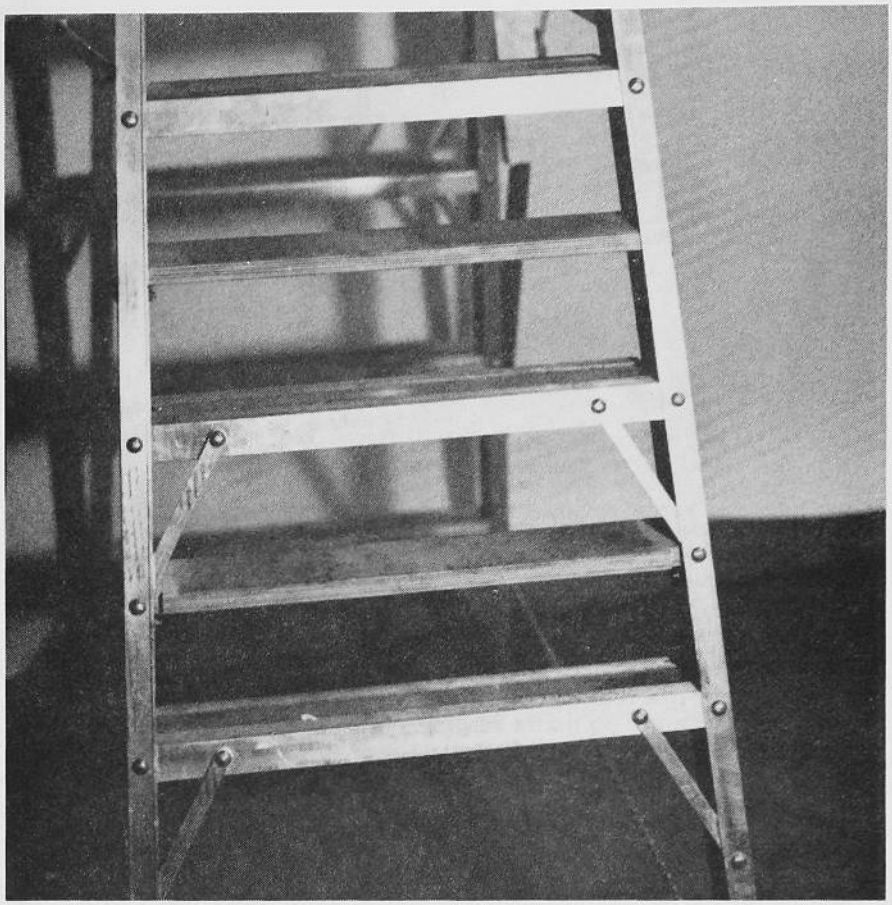
The cake pan has handles on two sides and nests perfectly into another pan permanently attached to the ladder under the top step. I simply load everything into it at the start of an observing session, carry it up and drop it into its mate on the ladder. Because it is always there at my fingertips, I usually don't even have to look down but can change eyepieces by feel.

Because my eyepiece tray sits under the top step, dew isn't a problem either. And when the ladder is folded for storage, the cake pan that is bolted to it is well within the confines of the opposing steps. Observing is much more enjoyable when I don't have to run up and down the ladder and then refind the image each time.

Since deep-sky objects are my favorite, Uranometria is a great resource. I like to start observing with a relatively bright object like NGC 7331 and then look for all the NGCs, ICs, and PKs I can starhop to. To do this at night with a dim red light means that the pages must be not more than 12 inches from your eyes, otherwise they are hard to read. What I needed was a "floating" observing table.

The answer came in copying the parallelogram type of mount some observers use to support binoculars. I fabricated my parallelogram from four 20-inch lengths of 0.125x1-inch flat aluminum stock. The four arms are bolted at each end, in pairs, to a short post of 1x1-inch square aluminum tubing. There is an 8-inch separation between upper and lower pairs. Between the post-arm joint are large thin nylon washers that give the unit a smooth motion that is free of binding. The geometry of the parallelogram always keeps the outer post in a vertical position throughout its range of travel.

The observing table mounted on the parallelogram is a simple 18x 24-inch piece of 1/4-inch plywood with a 6-inch length of 1.5-inch diameter thin wall tubing epoxied perpendicular to the bottom. This assembly slips over the outer support post of the parallelogram because the inside diameter of this round tube is equal to the hypotenuse of the 1-inch square tube. The table rotates freely to any position, and, very importantly, it can be easily removed for storage when the ladder is put away.



Just like my dental trays, the eyepiece tray fits into a tray that does not have handles. The table can be raised above the top of the ladder.

I wanted to avoid using a long balance arm with a counterweight, which would have made the parallelogram ungainly and might have posed a hazard for people walking by in the dark. Looking at the X-ray heads in my office which are supported by parallelograms, I've noticed that the trick is to use a very long spring. Their length means that the spring tension remains relatively constant when the unit is moved up and down.

I connected one end of a long 80-pound coil-spring to the bottom of the ladder and the other end to a rope and pulley. The rope runs through another pulley to the outer support arm. The spring is inactive in storage, but when I'm using the ladder I activate the spring by pulling the rope a foot or so and wrapping it around a boat cleat on the lower support post. The spring and the entire table assembly are mounted onto the opposite side of the ladder via a door hinge so it can swing out of the way freely.

When it's time to close down observing and go home, I remove the eyepiece tray and table, release the tension on the parallelogram and fold the ladder. The entire assembly remains attached to the side of the ladder along the rails. Only the outer support post protrudes a little.

All things considered, my customized observing ladder has performed better than I expected. I can spend 10 to 20 minutes at a time on the ladder working a 10-degree-square piece of sky in total enjoyment. Observers with equatorial telescopes have asked me how I can tolerate the lack of a clock drive. The question seems strange to me. With the telescope and ladder matched properly, I can single-handedly guide without fatigue for an entire night. Now the only thing remaining to do is muffle the Star-Wars-like sound that the spring makes when I push the ladder around. It really wrecks the mood.

David Kriege
923 Stony Road
Lake Mills, WI 53551

The Nuances of Optical Testing

Optical work is unlike other forms of manufacturing, in that every component comes out a little different, even if exactly the same manufacturing steps have been used. There are so many variables that affect the quality of work that consistent optical quality can be realized only if the maker is committed to stringent quality control.

It has recently come to light that certain manufacturers of the more popular telescopes and optical components, at some time in the past, relaxed their standards to the point that product quality was inconsistent and some optical systems sold were seriously flawed. Having encountered more than my share of these products, I now regard the quality of optics suspect until I have checked them myself.

Some observers and telescope makers, after becoming aware of such problems, are inclined to tell everyone to test their optics to reassure themselves that they are indeed as good as advertised. However, this is not as easy as some might think. Optical tests can be difficult to apply and difficult to interpret. In fairness to the manufacturers of optical instruments, and to their trusting customers, we believe that the readers of *Telescope Making* should be aware of the pitfalls as well as the power of optical tests.

This article, therefore, details some of the factors that complicate the issue of optical testing. We present these testing "nuances" in the earnest hope that the results of tests that *Telescope Making* readers carry out on their own and other people's optical systems will be both fair and accurate, and that misunderstandings about the quality of commercial products will be avoided, thus saving both manufacturers and customers a lot of trouble.

Testing Methods

The optical quality of a telescope can be assessed in the field with the simple star test or indoors with a "bench test" like the Ronchi or Foucault test. To my mind, the bench tests are more rigorous and are generally easier to perform and interpret. Unfortunately, critical bench tests usually require auxiliary optics and are out of reach of many observers.

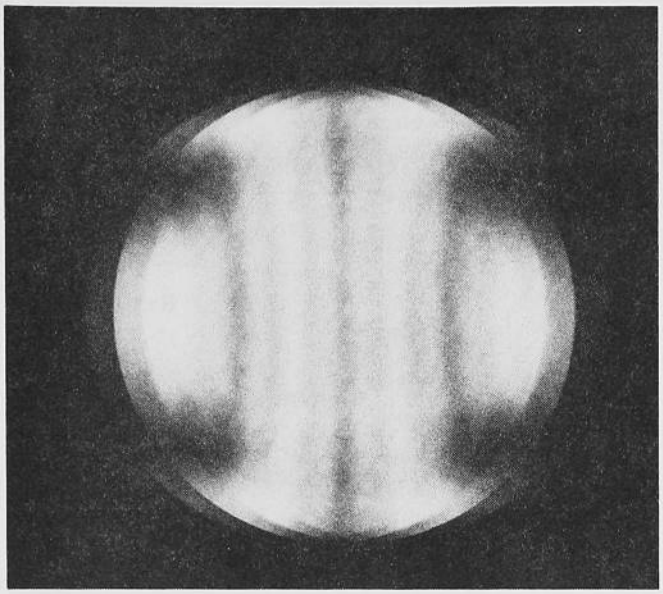
Careful consideration must be given to the environment when testing. Measures must be taken taken to dampen the vibrations originating in the telescope mount when field testing and in the supports when bench testing. Just as critical star testing requires good seeing, critical bench testing requires a room that has steady air conditions. In winter local sources of heat should be turned off and furnace vents should be closed to avoid generating air turbulence. In summer, air conditioning should be shut off and the room allowed to stabilize.

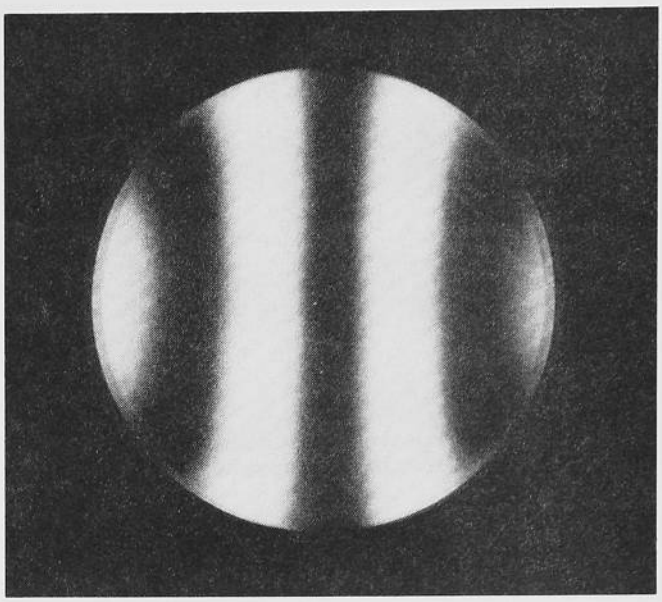
Star testing in the open air requires special consideration of the telescope being tested. Telescopes vary in their sensitivity to collimation and thermal changes. If a telescope has been carried out of the house, testing is best done when the outside temperature is close to the storage temperature, and collimation must be carefully checked and corrected even if it is only slightly out. The telescope should be allowed to come to equilibrium with the outside air temperature before critical tests are carried out.

Star Test The star test is the most accessible test to telescope users because all you need is your telescope and a clear steady sky. In the star test the quality of the image is examined at high power. Figure defects can be identified by their effect on the diffraction patterns of in- and out-of-focus star images. The star test is somewhat subjective, and the outcome depends on the observer's skill and testing experience. The star test should not be considered a pass/fail test unless the observer is very experienced and has tested many telescopes in this manner. However, if a telescope "passes" the star test with flying colors, there is no real need to carry out further testing except to satisfy your curiosity. However, should star test results be unfavorable, the telescope should be further tested with bench tests.

The star test should be repeated with different eyepieces to eliminate the possibility of a faulty eyepiece affecting the results. While eyepiece quality is much more consistent than objective quality, it is still a factor to consider.

The star test is best for detecting astigmatism in the image caused by warped optics. But be cautious. If your eyes are astigmatic, make sure you wear your glasses when checking your scope! If you see astigmatism in the image, rotate your head about your observing eye. If the oblong image rotates with the rotation of





A Ronchi screen that's too fine (left) suffers from diffraction. Here, a 10-inch f/8 mirror tested with a 175-lines-per-inch grating appears to have a rolled edge. Much better bands are seen (right) with 60 lines per inch.

your head, get your eyes checked, because you have astigmatism. Check the telescope for astigmatism even if you have performed other tests that it has passed with flying colors. Tests other than interferometry are just not sensitive enough to reveal subtle astigmatism.

Optics that do not seriously affect star images at low and medium powers can still be mediocre performers on low-contrast details common to planets. In fact, good planetary images are more revealing of optical quality than the star test. (Owners of fast reflectors and Cassegrain-type telescopes may already be aware that the large central obstruction lowers image contrast even with perfect optics).

Contrary to popular belief, double star resolution is not a good test of optical perfection. In fact, even Lord Rayleigh himself said that slightly undercorrected optics will outperform perfect optics on double stars! This is so because the *slight* spherical aberration shrinks the size of the Airy disk (while enhancing the diffraction rings), allowing finer resolution to be achieved.

Star testing must always be done when the star is centered in the field of view; otherwise, off-axis aberrations in the objective and especially the eyepiece may seriously distort the image. Dick Suiter's excellent account of the star test appeared in the May 1990 issue of ASTRONOMY, and was reprinted in the September 1990 Orion Telescope Center catalog.

Ronchi Test Although they may look similar, Ronchi (pronounced Ron-key) bands should not be confused with much more sensitive interference fringes discussed later in this article. The Ronchi test is an easy-to-use variation of the well-known Foucault test. The subjectivity of the star test can be largely sidestepped by placing a Ronchi screen—a grid of parallel lines etched on glass or photographed on film—at the focus of the telescope in place of the eyepiece. The observer brings a bright star to the center of the field, then places his or her eye in the beam of starlight and looks through the Ronchi screen into the instrument. A pattern of lines will appear projected onto the optics; an excellent optical system produces a pattern of straight lines.

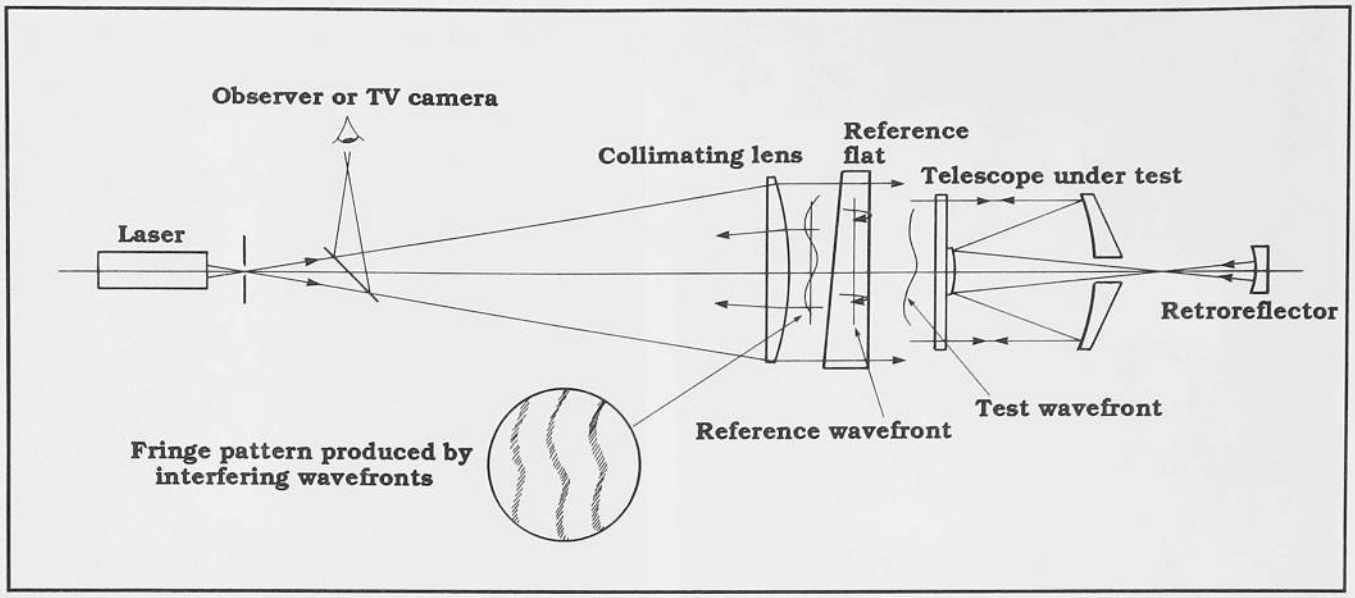
For good sensitivity, the screen should be close to the focus. You should see no more than two or three lines, or "bands" as they often called, across the aperture. For maximum sensitivity, move one band across the aperture and watch for subtle inflections on the band's edge. My experience has shown that the Ronchi test used with starlight is fine for detecting gross figure errors but requires more controlled conditions to reveal more subtle figure errors.

Let me illustrate: In one instance I checked a 10-inch f/4.5 Meade mirror set with a 100-line Ronchi screen illuminated by starlight. The lines looked quite straight. When a custom-made 6-inch f/4 later outperformed the 10-inch, its owner asked me to bench test the optics. To our surprise, the primary was out by about 1/2-wave at the edge, the worst placement for a zone because even a narrow zone at the edge occupies a large percentage of the area of the mirror.

Another 10-inch reflector, this one from Coulter, that I tested at a star party displayed Ronchi lines under star light that were so curved it was clear that the mirror was seriously undercorrected. In this case the error was far worse than 1/2-wave. Some of the Schmidt-Cassegrains I have tested with this method revealed more or less straight but wiggly lines, betraying the presence of zones in otherwise well-corrected systems.

It is important that the Ronchi grating be matched to the focal ratio of the system being tested. The grating shouldn't be too fine because the diffraction effects from a fine grating can cause the edge to appear rolled down when it isn't. Slow focal ratio instruments—f/10 and slower—should be tested with a grating no finer than 50 to 80 lines to the inch. Systems with focal ratios between f/4 and f/8 can be tested effectively with a 100-line grating. Remember that an f/8 mirror at the center of curvature produces an f/16 beam because the radius of curvature is double the focal length but the aperture stays the same.

The Ronchi test with starlight is helpful for detecting gross figure errors. There is too much interference from the atmosphere to reveal small defects, and the sensi-



tivity will vary with the telescope's focal ratio. A 1/4-wave zone, for example, will be more evident in an f/10 system than it will be in an f/4.5 system. (This does not apply to the star test in which the image is analyzed at high power.) My feeling is that if you can see obvious defects with the Ronchi test and starlight, the telescope's optics have some serious flaws.

Ronchi gratings etched on glass can be purchased from Edmund Scientific at 101 E. Gloucester Pike, Barrington, NJ 08007. One-inch square gratings with 50 and 100 lines/inch are $7.65 and $8.15 each, and are catalog numbers B30,511 and B30,513, respectively.

Foucault Test The Foucault test is very similar to the Ronchi test but requires more experience to interpret. A good set of optics tested with starlight and the Foucault test will produce a clean "null," that is, an even greying of the optical system when the knife edge cuts into the beam of starlight. This test is difficult to use on a telescope under the stars unless the mount is solid and equatorially driven, and the atmosphere is steady. Astrophotographers perform the Foucault test when they knife-edge focus their cameras. The Foucault test is well suited to bench testing of parabolic mirrors and complete telescopes. However, unless a null test is used, a parabolic mirror at the center of curvature produces dark shadows. Subtle zones are lost in the shadows of large fast mirrors.

As with the Ronchi test, the sensitivity of the Foucault test decreases as the mirror's focal ratio becomes faster. The classic Foucault test requires some experience to interpret and must be applied carefully to determine the mirror's true quality.

An excellent article on simple Foucault testing of parabolic mirrors for beginners and analyzing the results with a computer program listed in the article was published the February 1990 issue of *S&T*. Dick Suiter's shareware program MIRROR 2.0, and its predecessor GENMIR described in *TM#32*, carry out a sophisticated analysis of zonal readings and compute the best-fit paraboloid for any set of zonal measures.

However, the most accurate way to test a Newtonian primary, especially the larger fast mirrors popular today, is with the Foucault test combined with auxiliary optics, as in the autocollimation or the Ross Null test (see *TM#39*).

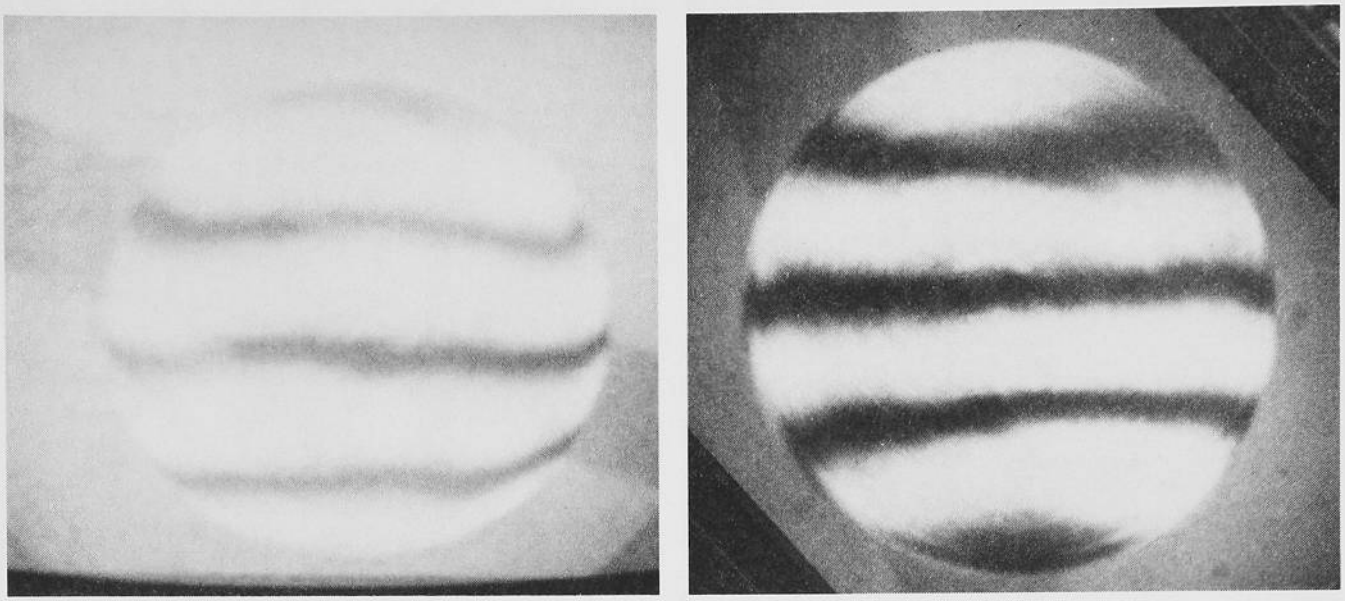
Interferometers produce a fringe pattern that compares a wavefront that has passed through the system under test with a wavefront from the reference surface. The telescope in the setup shown above is tested double-pass.

Interferometry The Foucault, Ronchi, and star tests are qualitative rather than quantitative tests, because when you see an error such as a zone—an error that you can see and you know is there—the test won't tell you the magnitude of the error. If you are testing optics with an interferometer, the magnitude of an error is easily determined because the wavefront generated by the telescope is compared with a reference wavefront of known high quality in the interferometer. Unfortunately, interferometers are very specialized and expensive instruments that are found only in well-equipped optical shops.

A variety of interferometers are useful for optical testing. The Twymann-Green, point diffraction (see *S&T* February 1985), scatterplate, and other common path interferometers are detailed in *Optical Shop Testing*, edited by D. Malacara, but the interferometer of choice in optical shops, both for its simplicity and ease of use, is the Fizeau interferometer. Fizeau is pronounced Fee-zoh.

The Zygo Mark IV interferometer pictured in this article is of the Fizeau type. This particular interferometer, at the National Research Council of Canada, has two "arms" of different aperture. The instrument is mounted on a massive, vibration-isolated optical table. The four-inch aperture arm (to the right of the computer console) is designed to test flat and spherical wavefronts. It is coupled to the computer for automatic fringe analysis. The larger arm, with a Celestron 8 in place for testing, is strictly for flat wavefronts. The interference fringes produced in the instrument are examined on a television monitor.

Interferometric testing is surprisingly easy with a well-designed interferometer. The major difficulty in carrying out the testing lies not in testing itself but in supporting the optics. Because interferometers are notoriously prone to vibration, the optic under test must be held firmly enough to prevent shaking but gently enough to avoid introducing stress that could



Proper test conditions are essential for meaningful results. The 7-inch Starfire objective at left, tested at a static temperature, appears to have a bad edge. When tested while cooling (right), this lens proves excellent.

give an erroneous result. The mounts must have fine adjustments for precise alignment and to allow the optician to vary the fringe spacing and orientation.

The principle of operation of a Fizeau interferometer is quite easy to understand. A lens collimates light emanating from a laser-illuminated pinhole. The reference flat acts as a beamsplitter. Part of the light is reflected back from the reference surface into the interferometer and the rest proceeds to the telescope as a collimated bundle of light. The light passes through the telescope, comes to a focus, and diverges—only to be reflected back to focus and through the telescope again by a concave mirror called a retroreflector. The light passes back through the telescope—it makes a double pass through the telescope—and re-enters the interferometer. In the interferometer, the light interferes with the light that bounced off a high-quality reference flat. The resultant interference-fringe pattern can be examined visually or captured with a video camera for display on a television monitor.

The interpretation of the fringe pattern depends on the setup and the item being tested. In the case of the interferograms in this article, the telescope's overall wavefront quality—that is, how the optics behave as a unit—is tested. Because the telescope optics were tested in a double-pass setup, the separation between any two dark fringes equals 1/2-wave. That is, if a defective zone displaces a fringe a distance equal to the overall spacing of the fringes, then the zone is in error by 1/2-wave. (See the July 1990 *S&T* for a simple water-immersion Fizeau interferometer.)

Interferograms are relatively easy to interpret when the fringes are relatively straight and the optical quality of the telescope is good. Interpretation gets more involved when severe zones are present, and is further complicated by aberrations like astigmatism. Advanced interferometers like the Zygo Mark IV have fringe analysis software that can, within limits, interpret interferograms and show the results in tables or graphs.

Testing Telescope Optics

The telescope optical systems that I have personally tested have ranged from near perfect to extremely bad. The best systems show images that would satisfy the most demanding observer; the worst everyone would agree were not useable as astronomical telescopes. However, these tests are capable of uncovering optical problems that would not bother the average observer, so good telescopes may show discernable flaws. Thus, merely indentifying flaws is not sufficient. The goal of testing is quantitative: *How* good are the optics?

Measuring the zonal focus error is a quick way to get a rough handle on the magnitude of zonal and figure errors. To find this, you measure the deviation between actual the focal length of the defective zones and what they should be. You can measure the focal error with the Foucault or Ronchi in a null setup.

Quarter-wave on the wavefront is generally considered the standard for astronomical optics. The focus error in millimeters for a diffraction-limited, 1/4-wave wavefront in yellow-green light (the part of the spectrum the eye is most sensitive to) is calculated with the following equation:

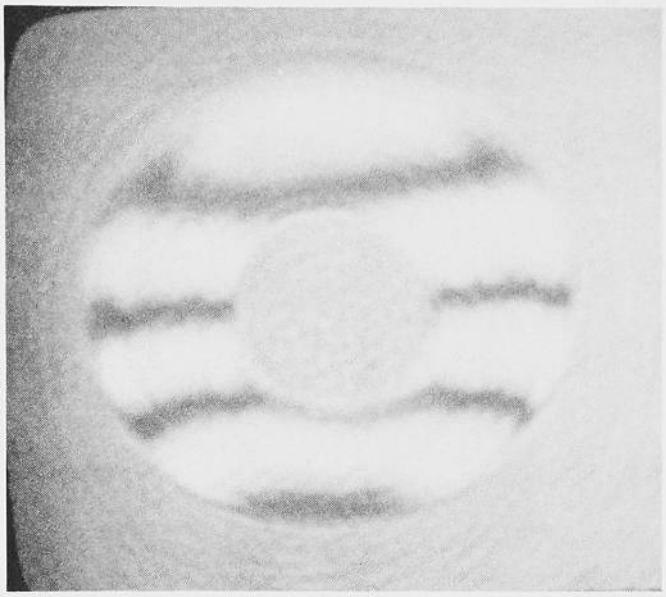
$$1/4\text{-wave focus tolerance} = 0.008(N)^2$$

where N is the telescope's focal ratio. For any f/4.5 Newtonian, a 1/4-wave focus tolerance amounts to 0.16mm. For an f/10 telescope such as a Schmidt-Cassegrain of any size, a 1/4-wave focus error is 0.8mm. These values can also be used when testing a telescope in a single-pass arrangement, as, for example, when you are testing with starlight.

When you test optics with an autocollimating flat so that light passes twice through the telescope—i.e., in double-pass—all optical aberrations are doubled. The focus tolerance should be doubled to 0.32mm and 1.6mm for f/4.5 and f/10 systems, respectively.

When the zone is deep, the focus difference can be easily quantified if the tester has an accurate longitudinal scale built in. The focus error of subtle zones, easily visible as faint shadows in the Foucault test or slight kinks in the Ronchi bands, are nonetheless difficult to quantify and require extreme care, a well-built tester and a steady bench.

Often in such cases I deliberately move the knife edge or Ronchi screen by an amount equal to the desired tol-



Questar 3.5-inch tested in double-pass shows nearly straight bands—sign of "damn good" optics. Severe astigmatism mars the performance of a C8 manufactered during the "bad years" of the Halley era.

erance. I then examine the shadows and bands to see if the movement produced changes that were greater than the defects observed. With this technique you are not actually quantifying the aberration, but you are making sure it is not greater than what is allowed. Testing like this requires patience and a lot of practice.

Practical Telescope Testing

Newtonian Reflectors Large fast parabolic mirrors are difficult to figure. The larger the mirror and the faster the focal length, the greater amount of material must be removed during figuring. When a great deal of stock removal is required, zones are almost inevitable. The area beyond the 70-percent zone of the mirror is particularly vulnerable to figure defects. Unfortunately, this part of the mirror accounts for half of the imaging area and also has the greatest effect on image quality because figure tolerance tightens up close to the edge. Furthermore, a significant portion of the central area is obscured by the diagonal. I spend at least 90% of the time working on the edge when figuring my large, fast mirrors. (See "High Finesse Figuring" in *TM#39*).

Let me illustrate with a specific example: A few years ago I tested a 10-inch f/6 mirror which the owner said gave excellent performance. I was surprised to see, by my standards, a rather zoney figure with the Ross null test. At first I was stumped, but then I noticed that although the area inside the 70-percent zone was rather rough, the area of the mirror from the 70-percent zone to the edge was velvety smooth. Had the locations of these figure errors been reversed—that is, with a smooth center and rough edge—the mirror would have been a disaster.

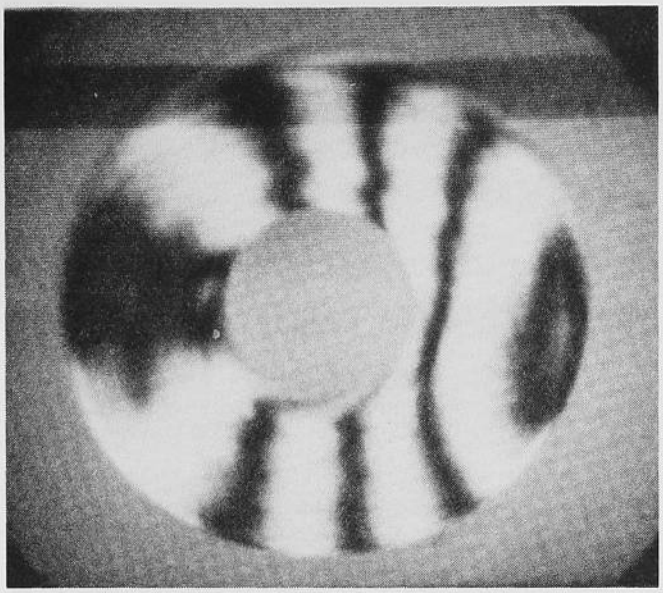
The large thin mirrors popular in today's Newtonians must be mounted properly. A proper mount means at least a nine-point flotation cell. I heard of one individual who used Velcro pads to mount his thin 10-inch Coulter primary! Another observer mounted a large thin mirror on 18 points—not in a flotation cell—with no control of the forces supporting the mirror. Makers of thin mirrors must help their customers understand how critical a properly designed flotation mirror cell is to good performance; many complaints of poor mirror quality can almost certainly be traced to poor mirror support.

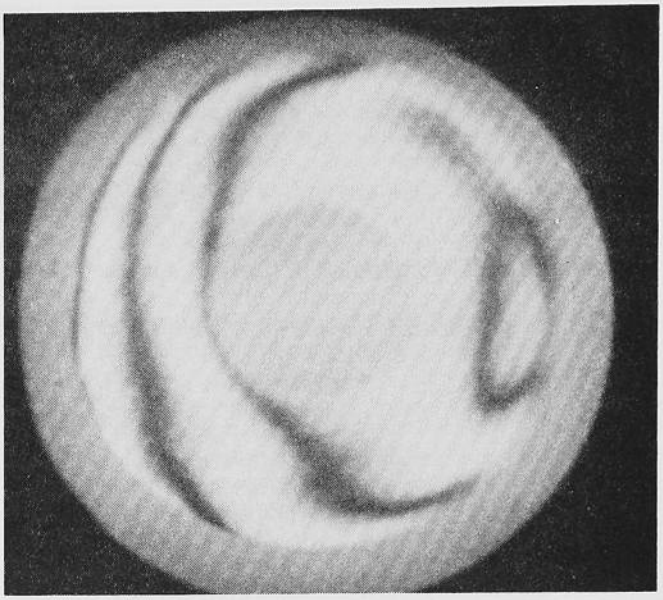
Astigmatism can be worked into thin mirrors if the blank is not properly prepared before grinding and polishing. The sheets of drawn glass that some mirror blanks are cut from are not flat. Only if the back surface is ground flat can the maker be sure that no bending or warping that will result in astigmatism is transferred to the front surface while the blank is resting on the surfacing machine's turntable. Astigmatism also results from poor mirror cells as the result of warping a perfectly good mirror.

This does not mean that the critical observer must shy away from properly made thin mirrors for fear of astigmatism. Several years ago I made a 12.5-inch f/5 mirror from a 1.25-inch-thick Pyrex blank. The back was first carefully fine ground flat and was perforated with a 1.5-inch hole in the center. The face of the mirror was then ground and polished while resting on shag carpet and an aluminum turntable. Throughout the process the mirror was never prevented from moving or "floating" on the carpet since force enough to restrain the mirror would also have been enough to distort it. The mirror was polished face up with a full diameter pitch tool to further avoid astigmatism.

The central hole was not intended for a Cassegrain optical system, as you might think, but for mounting the mirror via a central plug to restrain it laterally on the nine point flotation cell. A washer prevented the mirror from falling forward. I think that using the central plug rather than edge clips is less likely to stress the mirrors.

The mirror's performance made the extra effort worthwhile. Even at 600 power on a night with excellent seeing, no trace of astigmatism was visible. The moral of the story is that it can be done; thin mirrors can deliver excellent images. However, such time-consuming precautions in grinding and polishing are unnecessary with standard thickness blanks. I am amazed that thin mirrors are generally considerably less expensive than standard mirrors, even after the





Ronchi test bands (left) and interferometric fringes (right) are not the same. Although the Ronchi bands look fairly straight, interferometer fringes accent the spherical aberration and astigmatism in this 10-inch SCT.

less expensive glass cost is accounted for, because there is more work to making a first-class thin mirror.

Full-thickness Pyrex primary mirrors 10-inch and larger suffer from thermal effects that can cause a perfectly figured mirror to yield overcorrected star images. When there is a drop in temperature, the mirror shrinks slightly as it cools down. The shrinking causes the parabolic curve to deepen into a hyperbola, and the star images appear soft. (Thin optics don't suffer from this problem as much, since they do not have as much thermal inertia.) In the old days, when a 1:6 aspect ratio was the rule, opticians often undercorrected the mirrors *very slightly* so that under typical falling-temperature observing conditions the mirrors would perform well.

Astigmatism in a Newtonian telescope can sometimes be attributed to the secondary. These mirrors are sometimes pinched in their cells. The larger Coulter secondaries often do not fit the popular Novak holders because they are ground elliptical and not molded to a consistent size. Force fits are a sure way to warp optics and cause astigmatism. Cementing a flat to a plate can also induce enough stress to cause astigmatism if the mirror is too large or too thin, or if the wrong cement is used.

Schmidt-Cassegrains Careful collimation of SCTs is critical to optimum performance; before you do anything else, check the collimation of an SCT and correct any collimation errors. Take care in doing this because the collimation screws contact the secondary support directly and may distort the secondary mirror if they are too tight—and the owner's manuals for these telescopes warn you about this. A stressed secondary will produce either astigmatic (oval) or triangular star images associated with pinched optics.

The problem I have most often encountered in SCTs is poor smoothness of figure, or zones. Zoniness may be present when the overall correction for spherical aberration is nearly perfect. Zones soften star images and cause the planets to appear washed out. Even though the individual zone or zones may be narrow, their steep slopes can throw a significant amount of light outside the Airy disk.

Always check SCTs for astigmatism, even when a telescope has checked out free of zones and is perfectly corrected for spherical. One Celestron 8 (its wavefront is pictured in this article) looked great in the autocollimated Ronchi test, but the Zygo interferometer revealed astigmatism. At first I suspected that the scope was out of collimation, but I soon eliminated that possibility by examining the image of an artificial star (a ball bearing illuminated by a flashlight 75 feet away) and found collimation to be quite good. As I examined the star image, however, I noticed the characteristic oval star images of severe astigmatism. The axis of the oval image rotated 90 degrees when the telescope was inside and outside focus. I loosened the collimation screws on the secondary and gently recollimated the telescope to make sure the secondary wasn't warped, but saw no change.

Refractors Unlike concave mirrors that can be tested at the center of curvature with just a Foucault tester, refractors cannot be bench tested without an optical flat or a collimating telescope of known quality. All visual refractor lenses (as well as apochromats) are well-corrected only in the yellow-green part of the spectrum. Generally, blue light is overcorrected while red light is undercorrected. These differences in correction with color are called spherochromatism.

When assessing an achromat's imaging capabilities, test with a strongly colored yellow-green filter to eliminate the red and blue. You should see good correction for spherical at yellow-green wavelengths. You may also wish to test the objective with red and blue filters, but remember that your eye is not very sensitive to figure errors you may see because it is not very sensitive to deep red and deep blue light.

Overall correction for color is generally expressed as the difference in focal length between the yellow-light (e) focus and the red and blue (C and F) focus. A widely accepted rule of thumb is that the focus shift should be 1/2,000 of the focal length or less. You can measure this focus shift on the bench in autocollimation by determining the best null position for yellow-green and for red and blue, or simply by measuring the best focus

Ceravolo's Guide to Optical Jargon

Jargon and subtleties can easily mislead and confuse all but the most experienced optical-component buyer. The following brief guide defines some of the terms telescope makers are likely to encounter in the optical marketplace.

1/4-wave wavefront The wavefront is the near-spherical shell of light converging toward focus. The term "wavefront" in the description implies that the entire instrument produces no error greater in amplitude than 1/4-wave. In other words, the difference between the highest peak on the wavefront and the lowest valley is equal to or less than 1/4 of a wavelength of light. A mirror that would produce a 1/4-wave wavefront by itself may not produce a 1/4-wave wavefront in a Newtonian telescope because a poor diagonal has introduced errors. The quality of the wavefront after it has interacted with the last optical surface defines the quality of the image seen through the eyepiece.

1/8-wave mirror This is another way of describing a telescope mirror that gives a 1/4-wave wavefront. Use of the term "mirror" implies surface, and surface figure errors are doubled on the wavefront in reflection because the light rays must travel both into and out of a defective zone, say a depression, doubling the mirror surface error on the wavefront. Aberrated rays lag behind the unaberrated rays by twice the depth of the figure defect.

±1/16-wave mirror This is an even more attractive way of describing a 1/4-wave wavefront mirror. No hill or hole is greater than 1/16-wave relative to the *average* surface. The total peak-to-valley error is double this, or 1/8-wave. Because figure errors are doubled on reflection from a surface, the wavefront suffers from a 1/4-wave aberration.

1/14-wave-RMS wavefront Yet another way to talk about a 1/4-wave wavefront. RMS stands for "root mean square." Peak-to-valley error gives you an idea of the magnitude of the worst zone on the mirror, but can be misleading because a 1/4-wave bump in the center of the mirror is not as damaging to the image as a 1/4-wave edge error. The RMS rating is an attempt to address such inequities with an area-weighted statistical measurement of the error. To obtain the RMS error of a mirror with a smooth 1/4-wave peak-to-valley error, you would measure the error at each point on the surface, square the error, take the average, then extract the square root. Because much of the mirror surface deviates far less than 1/4-wave from ideal, the RMS error is numercially smaller than the peak-to-valley error. Note from this that RMS error can be misleading unless you also know the peak-to-valley error.

Diffraction-limited optics Yet another way of describing a system that produces a 1/4-wave wavefront. This term implies that image quality is limited more by the physical nature of light than the quality of the optics. Although "diffraction-limited" is often taken to mean "perfect," it is important to remember how demanding a skilled observer is of optical quality. Optical theory tells us that a 1/4-wave error in the wavefront causes *noticeable deterioration* in image sharpness and contrast. Planetary observers insist that they can see the deleterious effects of 1/20-wave errors in the wavefront.

—

All of the terms defined above place quantifiable limits on optical quality and can easily be verified with the proper test equipment. We now explore some of the non-quantifiable phrases that abound in advertising optical goods. No real claim is made with these phrases, but the unwary buyer may believe they signify quality.

Null-Figured This phrase describes the type of test used to check the optical quality during fabrication. It makes no claim about the quality of the optical system. Autocollimation, the Dall Null, and Ross Null tests are examples of null tests. Null tests are superior to zonal tests, especially when applied to large fast mirrors. When the optics in question are examined with such a test, there will be a null or a complete greying of the aperture indicating that the light rays from all over the aperture are coming to a common focus.

Hand-Figured This phrase describes the method of manufacture and makes no claim about optical quality. The phrase capitalizes on a peculiarity of optical production: The random and inconsistent polishing action of a polisher driven by a sometimes unpredictable but skilled human being can produce very smooth surfaces. Although automation usually means consistent quality and speedy production, the automatic polishing machines commonly used in the optical industry usually mean zones. Unless this phrase is backed up with quantifiable standards, it amounts to little more than window dressing.

100%-Corrected, No Zones This statement implies high optical quality. The 100% corrected portion implies that the wavefront bouncing off a parabolic mirror or passing through a refractor objective is perfectly spherical—that is, neither under- nor overcorrected. The word "no" in the phrase "no zones" implies that the wavefront is perfectly smooth and totally free of irregularities. Such claims are impossible to achieve in the real world. Tolerances must be supplied to make these terms meaningful.

Laser-Tested Most people equate lasers with high-tech testing. Unless the laser is used in an interferometer, however, it is just another, albeit rather useful, light source no better for optical testing than a standard light bulb.

Performance limited by the laws of physics The laws of physics that define the image in a perfect optical system also predict the less-than-optimum image that will be produced by a poor optical system. This statement is not untrue; it is pure hype and says absolutely nothing about optical quality.

The Zygo Mark IV is a Fizeau-type interferometer. In this picture, a C8 is under test in the larger arm of the instrument. Peter Ceravolo's hand touches the fine-motion controls of the mirror that returns light through the 'scope.

in each light for a star image. The shift is fairly large, typically more than a millimeter for a 6-inch f/15 doublet. Divide the shift by the focal length. With well-corrected apochromats, the focus shift may be so small that it is hard to measure.

Refractors are often thought to be largely immune to the temperature effects that plague reflectors. While this is true of the smaller achromats, the same cannot be said of three-element apochromats. The steep curves call for thick elements, making a three element objective very thick and giving the lens substantial thermal inertia. This fact, combined with sensitive glass, causes some apos to be quite sensitive to temperature changes. Consequently, just as full-thickness mirrors sometimes are, lenses may be figured for the falling-temperature conditions they are likely to encounter in the field. As I personally discovered, the lens may have entirely different characteristics when bench tested in a stable temperature environment! Check these telescopes when the storage temperature is not drastically different from the outside temperature, ideally in the spring, summer or fall.

Know What to Expect

As an optician, I consider most telescopes and optical components sold to the amateur astronomical community a real bargain. Very few amateur astronomers, or telescope makers, have any idea what it takes to produce telescope optics that are truly accurate to 1/10-wave. To do this continuously on a production basis with optical systems as complex as, for example, the Schmidt-Cassegrain is no small feat. I am amazed that sophisticated optical systems complete with mountings and other gadgetry can be sold to the consumer for a few thousand dollars. When I was testing an SCT with a 1/2-wave wavefront on the Zygo interferometer, an optical engineer who happen to walk by remarked that the telescope's optics looked pretty good. I told him I did not agree, and he asked me what the telescope cost. When I told him a few thousand dollars, his reply was, "Bloody hell! What do you expect for that money!"

While some commercial telescopes may be a bargain, even if they don't quite achieve advertised quality, the astronomical community should not encourage commercial firms to misrepresent their products, intentionally or otherwise. In my opinion, this can only be accomplished when buyers test the products they have purchased and return them if they do not meet advertised specifications. I have personally tested and returned many Newtonian mirror diagonals sold by Meade because they ranged from five to twenty times worse than the advertised 1/10-wave flatness. These flats were advertised as 1/10-wave elliptical flats for the DS-series reflectors until March 1988. When the ads for these telescopes reappeared in the August 1989 *S&T*, the 1/10-wave phrase had been removed and replaced by "matching elliptical flat secondary." Although the quality of flats may be the same, the advertising is honest. I also understand that Meade now tests every one of its diagonals with an interferometer so that no "lemons" are likely to be shipped to customers. These aluminized and overcoated diagonals, priced at roughly $100 at the time of this writing, represent an excellent value.

Commercial firms that commit themselves to quantifiable standards in their advertising should, I believe, be prepared to provide serialized optics and a test sheet with photographic proof of optical quality. The interferogram of a Celestron 8 reproduced in this article reveals optics suffering from several waves of astigmatism—yet this telescope was supplied with a certificate purporting 1/10-wave optical quality! A Ronchigram of the telescope in a double pass autocollimation test (with a *maximum* of three Ronchi lines across the aperture) would suffice, or better yet, interferograms so the quality can be easily quantified. Unsupported certificates are hardly credible.

As an amateur astronomer I had become so accustomed to phrases like "1/10th wave optics" used in advertising that I was surprised *not* to see the phrase in telescope advertising. But such "wave-inflation" has caused amateur astronomers to become desensitized to the expense involved in making true 1/10-wave optics consistently. If the amateur community as a whole has been happy with 1/4-wave optics, there is no need to represent 1/4-wave as 1/10-wave or better.

These rather harsh condemnations are not directed at the opticians who actually manufacture the optics but at the management and marketing people who claim a level of optical perfection that the opticians know and acknowledge to be difficult or impossible to achieve on a mass production basis.

But let us look at our own standards. Although I believe that commercial optics should meet advertised standards, I also believe amateur astronomers should not demand perfection from commercial optics. Rare indeed is the optical system that is free of flaws. The optical tests amateur astronomers use are sensitive enough to reveal flaws considerably smaller than the *advertised* specifications.

The bottom line, whenever you evaluate optics, is that the perfect optical system is the unaffordable optical system. Keep it in mind.

Peter Ceravolo
P.O. Box 27092
Gloucester, Ontario
K1J 9L9
Canada

Designing a Breakdown Telescope For Club Use

Bob Drew stands beside the 17.5-inch Edmonton Centre, RASC Dobsonian telescope. All photos in the story by Randy Pakan or Bob Drew.

The Edmonton Centre of the Royal Astronomical Society of Canada completed its first 17.5-inch Dobsonian in 1982. Like most Dobsonians of that era, it was sturdy, large, and heavy. However, because it could be transported only in a full-size van, members used it only sporadically. At an Edmonton Centre meeting in November 1987, the membership accepted my design and authorized my coordinating construction of a new telescope designed for easy breakdown.

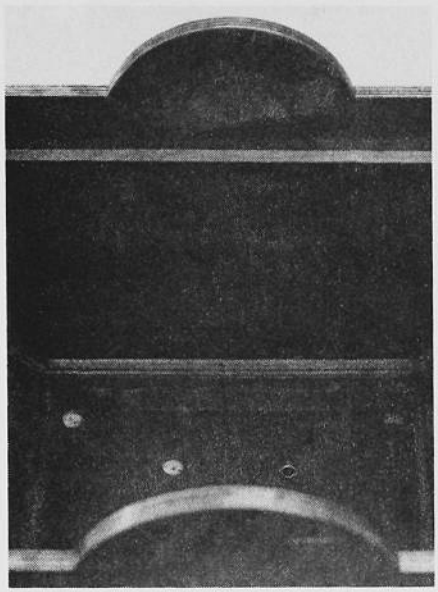
Telescope Making has reported a variety of approaches in solving the breakdown scope challenge. I was particularly impressed by the design of Ivar Hamberg, published in *TM#17*. I will describe in this article several solutions that have evolved from the previous literature in response to designing and constructing telescopes for the many users in an astronomy club.

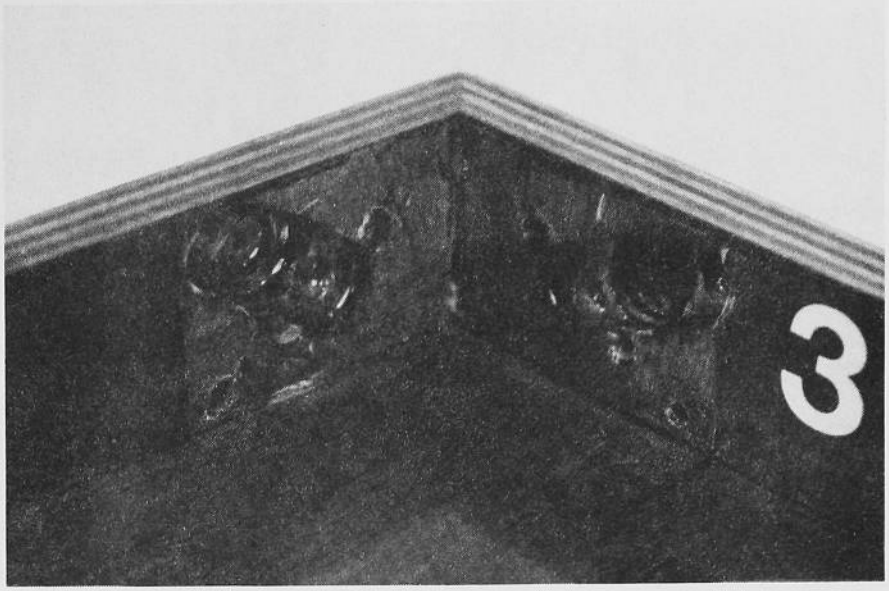
My design goals were: 1) to make the telescope reliable and easy to assemble accurately in the field, 2) to minimize the eyepiece height when the telescope was pointed at the zenith, 3) to make the telescope light and transportable, 4) to make the telescope durable. I believe that we achieved our goals and that many telescope makers and astronomy clubs will find my design of interest.

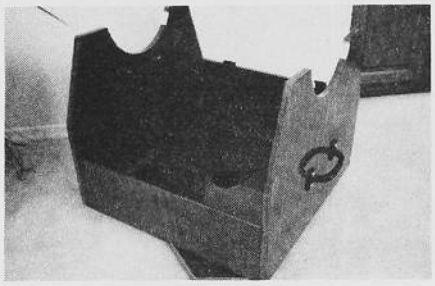
Durability proved to be a tough constraint. Components cannot be as light as they could be in an innovative private telescope. Any component that is unduly delicate might prove to be an Achilles heel. An owner/builder soon learns to work around weak or troublesome features—but a club telescope that must be assembled in the dark and will be used by minimally-trained astronomers. Furthermore, the club is likely to insist that the instrument last a number of years. All of our design decisions took durability into account.

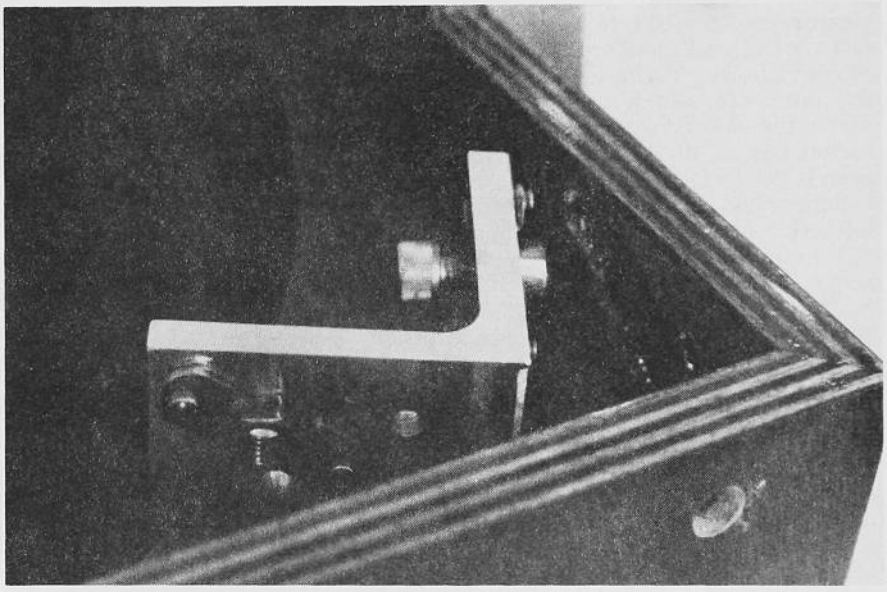
Another key design consideration was to keep the mirror box and rocker box low for portability. We saw that if these components did not exceed 25 inches in height when the mirror box was nested inside the rocker box, the combination would be low enough to fit into small station wagons, ensuring that many club members would be able to transport the instrument. In use, the mirror box would be lifted out and rotated 90 degrees to rest on the altitude bearing Teflon pads.

The mirror box at the top of the trunion bearing is only 22 inches high. Unfortunately, this gave us a very short lower moment, which required the addition of 32 pounds of permanent lead counterweights. It clearly would have been better to design an ultra-light upper tube and place the trunion bearings at the center of gravity, avoiding coun-









terweights entirely, but the telescope would have been less robust than we wanted. As it is, the entire telescope weighs 172 pounds. Because the rocker box and mirror box weigh a total of 140 pounds, two people must load it, but then one person can easily assemble it. Even with the excess weight, the telescope is 60 pounds lighter than its predecessor.

Also, because our telescope was intended to be used as a club scope, and because astronomers come in different heights, the less anyone has to climb on a ladder the better. When you finalize your design for a large aperture or long focal length scope, see if you can make the focuser low enough for someone standing on the ground to reach.

Major parts of the rocker and mirror boxes are finished to a high gloss. Corners of the mirror box showing captive nuts and their recesses.

Once you determine the four related optical parameters – aperture, focal length, focal ratio, and secondary to focus distance–you have set the irreducible minimum height of the focuser. If you determine that you want no ladders at all, this decision can ultimately set the largest aperture you can build. In our case, we started with the optics and built the telescope to have as low an eyepiece height as possible.

Early in the design process, draw out your plan. Some people have used full-sized drawings to make sure they have not missed something. I used simple 1/4-inch grid paper and good drafting instruments. I have recently tried making full-sized drawings to work out the design challenges on another scope. Banquet paper that you can buy from wedding supply firms is good for this. It comes in rolls 40 inches wide and 100 feet long, and for a reasonable price.

Rocker and Groundboard

To keep the telescope low, design carefully so as to add as little "waste" height as possible, particularly in the ground board and rocker box area. Starting at the ground level, we found that a ground board supported on 3/4-inch-thick pads on a radius of 14 inches does not hang up on most

types of ground surface.

How thick should you make your ground board? I recommend the minimum necessary to prevent flexure and to maintain contact with the Teflon pads. You can use plywood laminated on the bias, plywood skinned with fiberglas or other exotic cloths, or foam-sandwich construction. The latter may introduce other problems through compression or excess height. Two layers of 3/4-inch plywood worked fine for the ground board.

To reduce the height of the rocker, radius the mirror box in position to ensure all necessary clearances. To facilitate lowering the pivot point, we double-beveled the mirror box on both the front and the back. To stiffen the sides, we made the short rear board on the rocker box as high as possible, but even it is beveled for clearance.

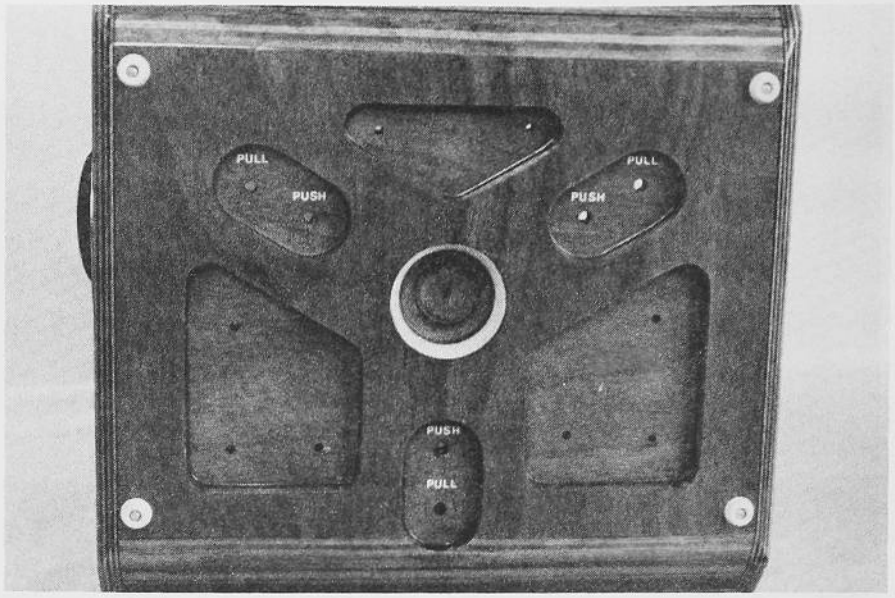
Remember when you design the telescope to leave enough room for the mirror cell hardware. In this scope, even the laminated cell board is beveled on the fore and aft sides. We left just enough clearance between the cell board and the bottom of the mirror box for collimation.

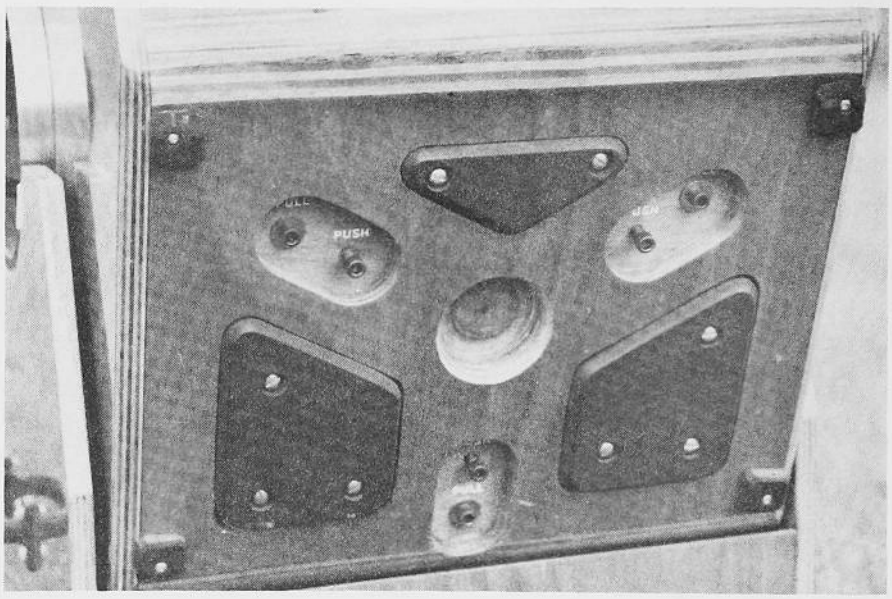
The bottom of the mirror box is made from two layers of 3/4-inch plywood laminated on the bias. The two layers were necessary for strength as an anchor for the cell board, and to protect the collimation Allen bolt heads during transport. Since counterweights were required to balance the telescope, we cut away non-essential areas in the bottom board before it was laminated. The lead weights were then poured, milled, beveled, and fitted into these holes.

The ground board pivot pin is not just a bolt. It is a 5/8-inch steel pin welded to a small mounting plate. The rocker box bearing is a 5/8-inch ball bearing, although a properly fitted bushing would likely work just fine. The mirror box is heavily gusseted and reinforced with fiberglass inside.

Plywood and Materials

Marine plywood which was used throughout also affords some advantages: the 9-ply material is stiffer than 7-ply is, it has no voids,





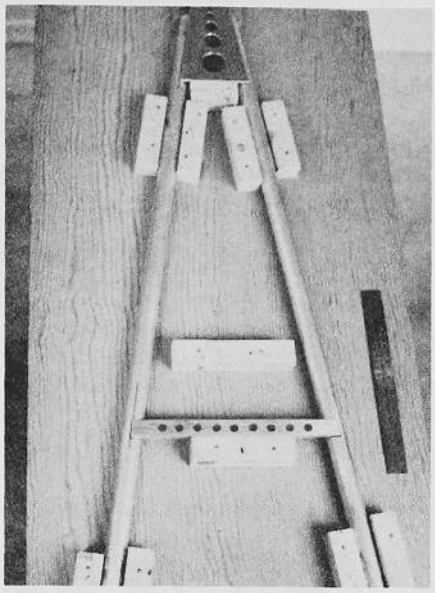
Recesses in the rear of the mirror box hold lead counterweights. Note that the corners of the mirror box are radiused and barely clear the rocker.

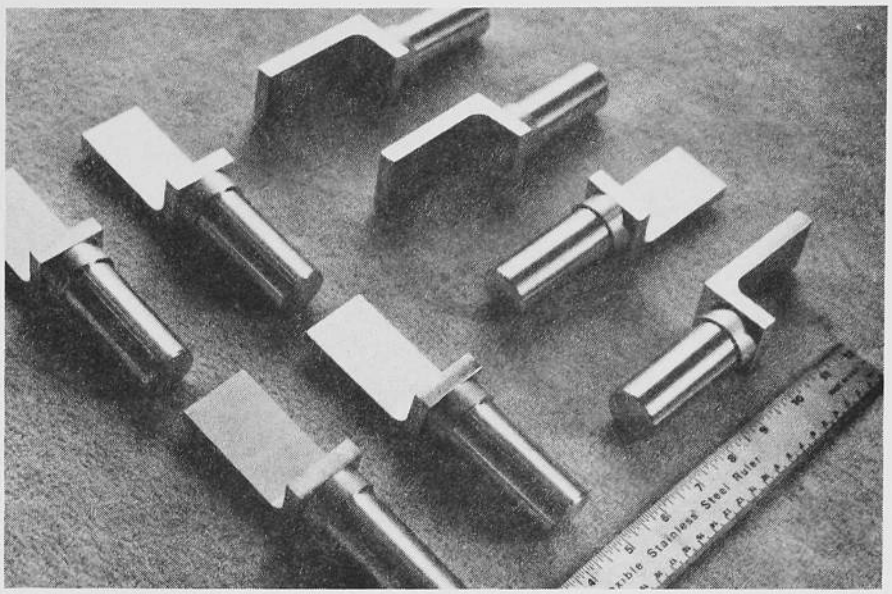
and the glue that laminates the layrs is waterproof. Because we had difficulty locating marine fir, we used 3/4-inch Gaboon mahogany. This gave a very aesthetic result and probably invited more sanding than necessary.

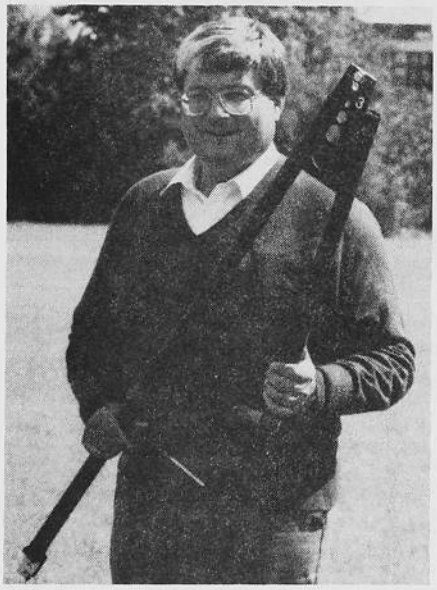
The twenty-seven wooden parts were saturated with three coats of West System Epoxy which, with microfibers, was also used as the bonding agent. Surfaces were sanded to beyond 600- or 800 grit and overcoated with two coats of exterior Varathane for ultraviolet screening. As it is moisture that causes the breakdown in wood components, all holes through the wood were epoxied and re-drilled.

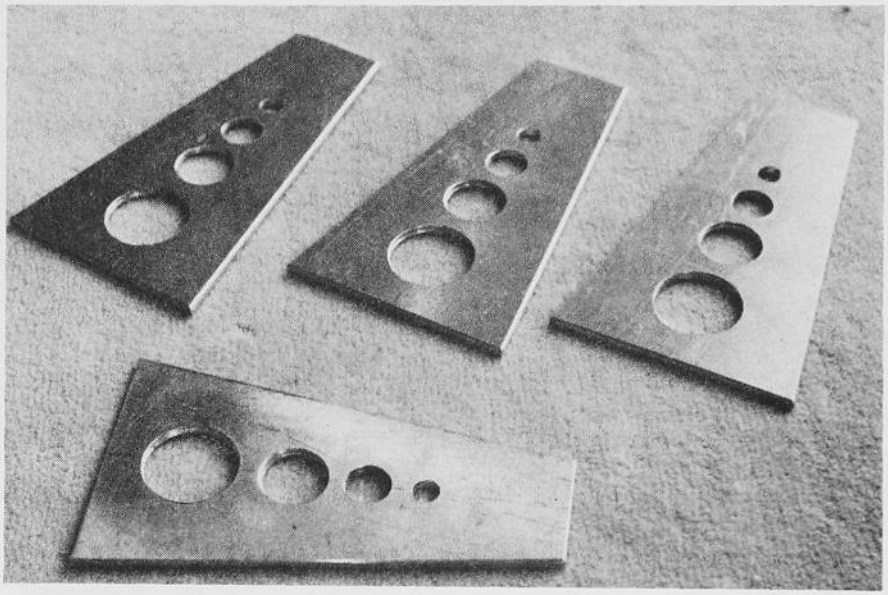
Safety precautions must be taken when working with and sanding epoxy. West System epoxy has been used widely in racing sailboat dingies and I am surprised that it is not used in more telescopes. It results in a very hard surface, which unfortunately is rather labor-intensive, but can yield a very smooth finish.

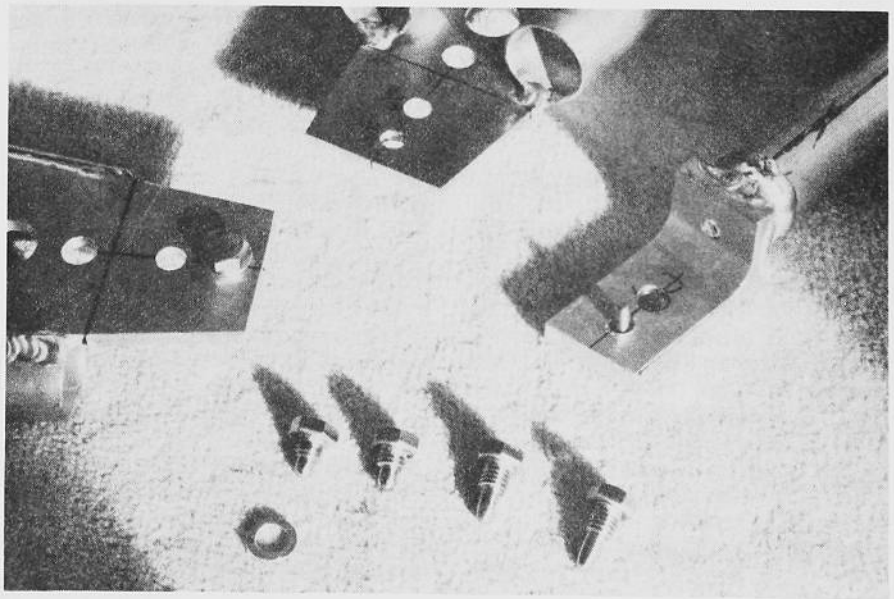
Cutting the plywood parts turned out to be a real pleasure. I had not done any carpentry since Industrial Arts in junior high school. For the project, I had access to a friend's cabinet maker's circular saw. It was a real pleasure to use. The fence did not wander even in long cuts, and all the resultant pieces fit like a charm. I even mitred the corners of









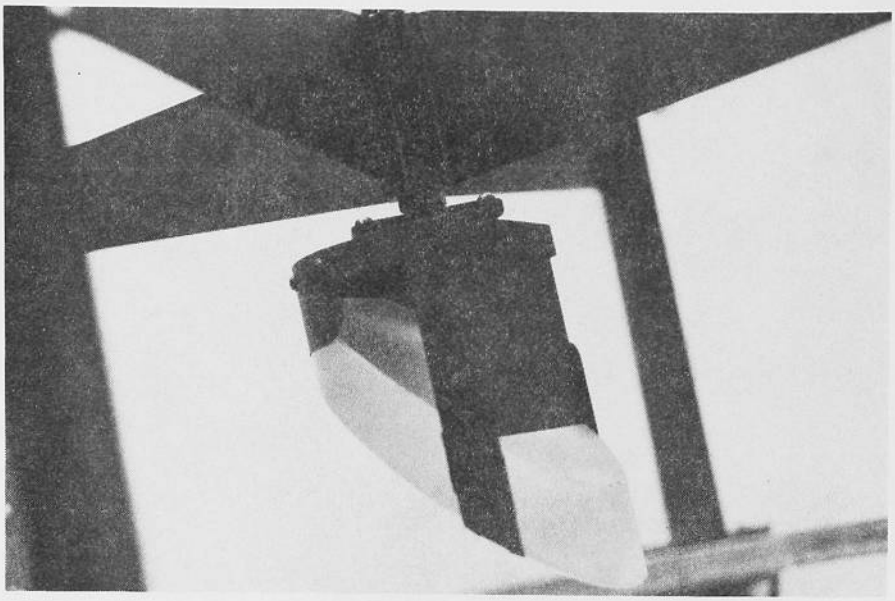


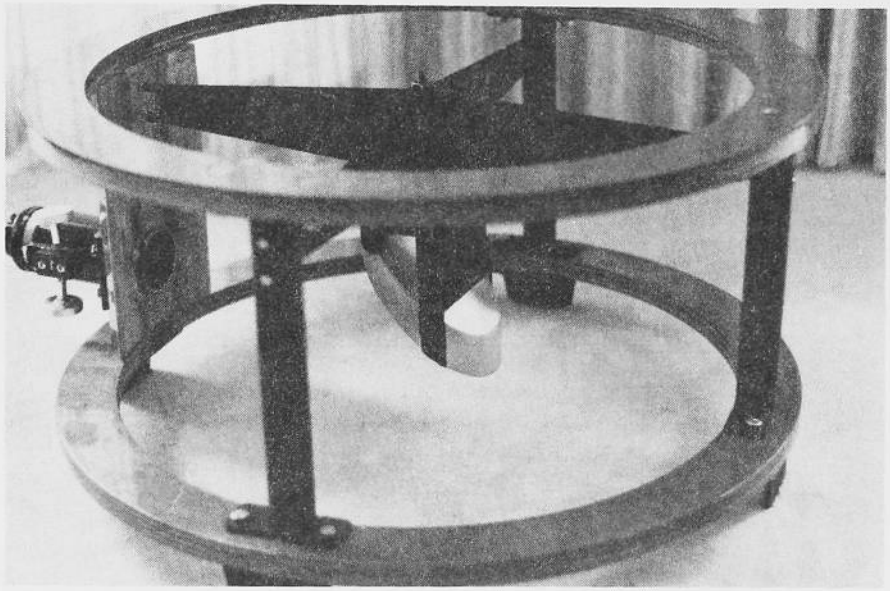
Plywood jig holds truss parts during welding. Lower tube inserts (at top) and aluminum plates (middle) are welded to truss tubing (bottom).

the mirror box which, although not necessary, was fun. The mirror box came out perfectly square, more by good fortune than skill. It was then that I learned that the 3/8-inch thick by 3x3-inch angle aluminum extrusion does not come out perfectly square and had to be trued.

Tube Trusses

If you have ever watched someone assembling a break-down scope with eight tubes flailing all over, you will understand my concern for how long the club scope might last when borrowers tried to assemble a light





Open diagonal holder promotes rapid cooling without stress. Upper end assembly has solid focuser board and thin-wall spider supports.

but delicate truss system in the dark.

The eight trusses are welded into four fixed A-frame tube pairs. The tubes are 1.25-inch with a 1/16-inch wall. The lower truss tubes, with solid aluminum plug inserts, were welded to the angle brackets which, in turn, carry the locator pins. The angle brackets were carefully milled for the necessary offset required when accounting for the different radius at the top and bottom of the truss anchor point on the scope.

We used 3/16-inch-thick aluminum angle brackets for the upper tube and upper truss webs to minimize accidental bending through misuse. The truss tubes use aluminium rod plug inserts milled to squeeze fit and were then welded. Welders will tell you that a plain butt weld would suffice, but the plug inserts strengthen the mounting hardware which itself is 3/8-inch angle aluminum.

We took great care with the truss web hardware. We milled 3/8-inch hex-head bolts to 1/4-inch to serve as locating pins. Stainless nuts were made captive with small welded stainless tabs which were then riveted to the upper webs and lower corner anchors. These pins very accurately locate the truss in shear while the captive nuts work in compression. This system is not prone to contamination which could affect collimation through misalignment.

There are also short aluminum plugs in the vertical tubes in the upper cage to prevent collapse where the spider bolts are mounted. The three vertical tubes themselves are welded to 1/8-inch flat tabs centered with the corresponding truss anchors to spread the loads. Offset was built into two of the tubes.

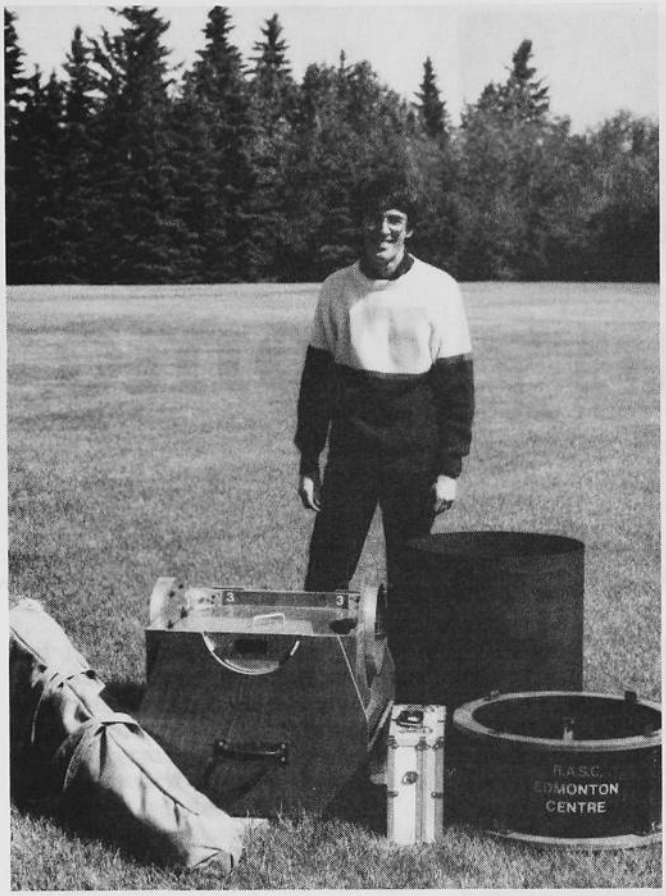
The truss tube pairs are welded to the upper web and also have a light weight channel cross-member 14 inches from the bottom. Structurally this is not necessary, but it does have three advantages: it prevents inadvertent damage to the "wishbones" during transport; it helps keep the tube shroud from collapsing into the light path; and it minimizes undesirable resonances. There is virtually no image jiggling. The trusses are not ultra-light; the four weigh 14.3 pounds.

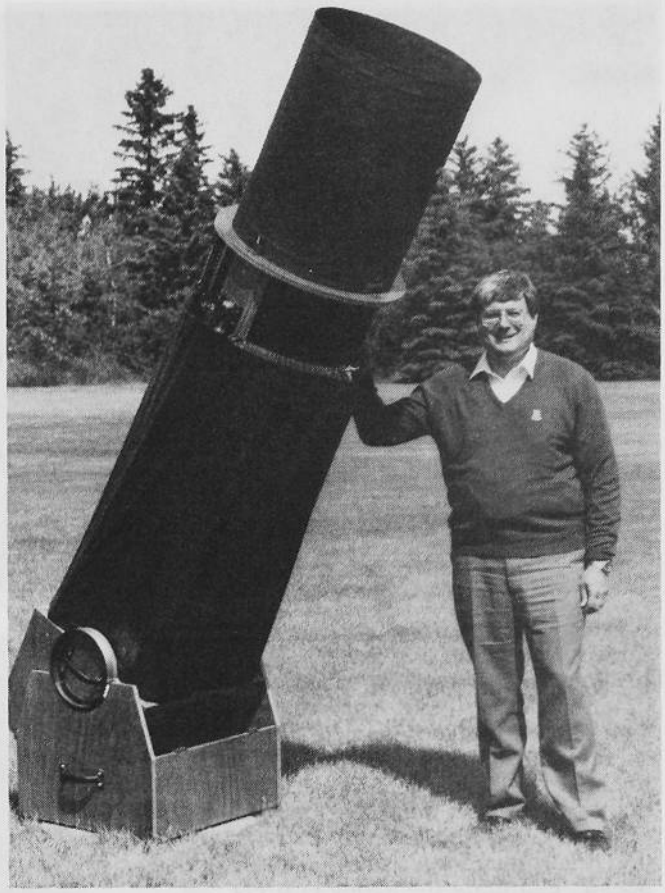
One important feature of this sturdy system is that each truss A-frame can stand alone quite rigidly, and the upper tube can be bolted on at a leisurely pace. The trusses are 48.125 inches high with a base 18.25 inches wide. Although the trusses are almost interchangeable, I did not think it was necessary to jig up to the accuracy needed to make them interchangeable. Each truss pair is numbered to correspond to the mounting side on the mirror box.

Because the trusses are inside the shroud near the light path, we painted them with flat black Tremclad over an aluminum undercoat. Light path calculations were done by Bryce Hartwell, a very competent observer and astrophotographer. The trusses and scope were then built to these measurements. At first light, the designed nominal focus came in right on the money! The trusses are stored and transported in a large triangular cordura bag. Each truss has its own compartment and can be loaded in the dark.

Optics

If you order 4.25-inch secondary from Coulter Optics, you may find (as we did) that it does not fit a 4.25-inch Novak holder, particu-





Fully knocked down (left) and fully assembled (right) views of the 17.5-inch telescope. Note Cordura bag for the trusses and black tube shroud.

larly if the mirror's minor axis is 4.31 inches (as was the case with ours). The secondary was polished to better than 1/10-wave by member Barry Arnold of Arnold Optics in Sherwood Park, Alberta (a suburb of Edmonton). Barry Arnold also fabricated and donated a custom-mixed, innovative secondary holder to the club. It holds the mirror without inducing stress, while promoting rapid cooling.

The 17.5-inch Coulter primary mirror was originally incorrectly evaluated as being quite good. However, recent testing at Arnold Optics confirmed that it is astigmatic, as we suspected, and also badly undercorrected. We expect to remedy this in the near future.

Barry Arnold is the "local optician" referred to in Bryce Hartwell's letter about commercial optics (see *TM#39*). Known regionally for the exceptional flats he produces, Barry also makes primaries for amateur scopes. Without any fanfare, he has been supportive of our Centre.

While observing, we use a black 2.4-ounce ripstop nylon tube shroud. It has internal elastic cords and stoppers, top and bottom, and simply zips on with a 4-foot-long zipper. The length of the upper tube is only long enough to protect the secondary and spider.

To minimize stray light—and keep in mind we live in the Great White North—we also use a Kevlar and fiberglas laid-up baffle extension 26 inches long. It weighs less than 4 pounds and is attached with simple brackets and Velcro. (See "Newtonian Baffles" by Richard Berry in the Winter 88/89 issue of *Deep Sky*).

A Successful Club Project

With a club scope you have to try to satisfy everyone. Even the finder was a negotiated compromise. Active observers steadfastly wanted either a straight through or an Amici prism finder to give upright views. After checking many suppliers, we settled upon the 50mm Tuthill finder. This unit is convertible to either mode and weighs only 1.42 pounds, including the mounting base and collimation system. We also use a Telrad.

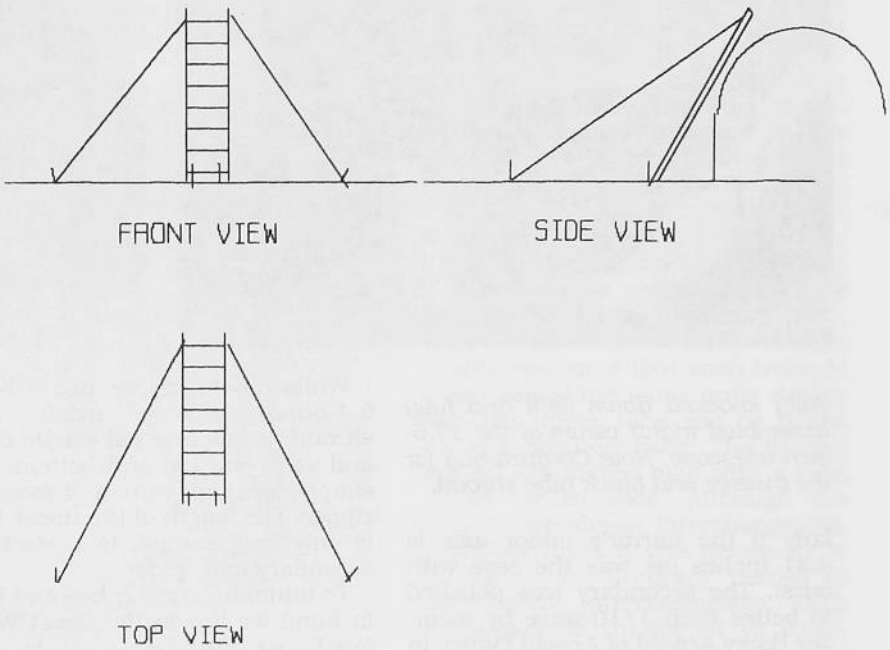
The project took approximately 1000 hours of volunteer time over a one-year period to complete. Eight club members pitched in at three or more work parties. Paul Campbell and I did about two-thirds of the project, while Randy Pakan and Bill Wells also made major contributions. Aluminum welding services were donated. The optics and related components cost only $1,400 Canadian. The materials, including reams of sandpaper, cost $1,100 Canadian.

The telescope has seen regular use locally in the past year. Our club was grastified last year when the telescope received awards at Riverside in May 1989 and at the Mount Kobau Star Party held near Penticton, British Columbia, in August.

After a year of use, the design and material appeared to have held up and the design goals seem to have been achieved. The eyepiece height at the zenith is only 73 inches — not bad for a telescope with a 78.2-inch focal length! We can now concentrate on the other part of the equation: observing.

Bob Drew
12207 Aspen Drive West
Edmonton, Alberta
T6J 2B7
Canada

How to Paint an Observatory Dome



Have you struggled with ladders and scaffolding, sprayers and brushes, long-handled rollers and other paraphernalia trying to get that darned dome of yours painted? In fact, how many amateurs have rejected the whole notion of building or buying a dome for just this reason? Well, here's a way to paint and maintain domes that, while it doesn't eliminate the agony entirely, certainly does make dome maintainance a lot easier.

A number of years ago I was stopped dead in my tracks when I took my son, Alan, to his Webelos scout meeting. His leader, Burton Riffle, is an expert when it comes to ropes and knots. What stopped me was a ladder standing upright in his front yard, apparently without anything to lean on.

The scouts weren't stopped, though. They went scrambling up and down the ladder, leaving flabbergasted parents dumbfounded. Upon closer inspection, I found that Burton had simply employed the principle of the crane to support the ladder. He had staked the base of the ladder down to the ground with sturdy steel rods and supported the upper end with heavy ropes tied off to two large trees. Burton called it an "air ladder."

Two years ago when the time came to paint my dome, I conjured up all sorts of elaborate ideas for scaffolding—but none promised to be either convenient or easy to put up. Then I remembered Burton's air ladder. So I went to the hardware store and got 75 feet of 3/4-inch hemp rope, made some heavy stakes out of scrap wood, and dragged out my extension ladder.

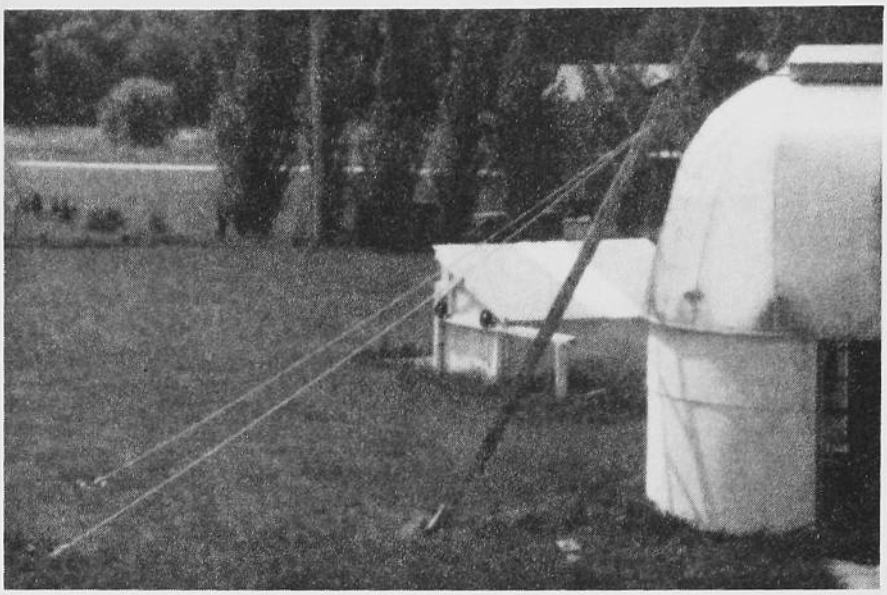
I threaded the rope through the tubular top rung and knotted it on each side of the ladder, although it might have been easier to cut the rope in half and tie the resulting two ropes to the top of the ladder. I would also suggest to anyone trying this that 100 feet of rope would have been better.

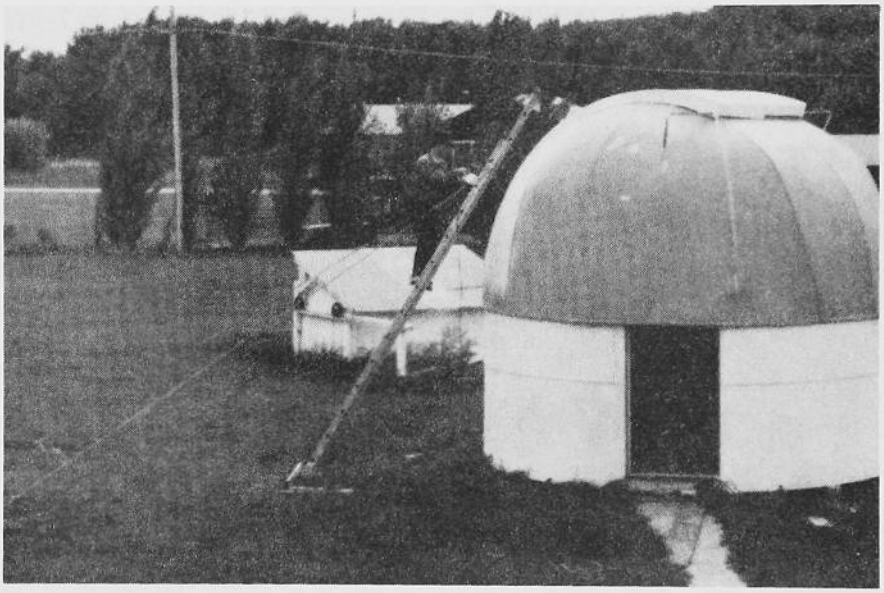
I leaned the ladder against the dome at an angle that would allow easy access to the top, extended it sufficiently, and staked it down. I estimated stake positions for the top supports based on the amount of rope available and the desired position for the top of the ladder. The stakes should be about three feet long and should be driven most of the way into the ground.

I tied off the ropes to these stakes and raised the ladder until it was 18 to 24 inches from the dome at its closest point. This allows clearance for the ladder, because when you put your weight on the ladder the ropes will stretch somewhat.

A few words of caution. Make sure you tie your knots properly. If you have doubts about this, get a book on knot tying or find an expert like Burton Riffle. A loose rope could lead to a damaged dome or broken bones. Keep in mind that the ropes should be tightened if they stretch. The ropes will stretch if the ladder is left in place for an extended period. Also, remember that ropes are affected by moisture, and that you may need to adjust them several times each day.

When you use the ladder, keep in mind that it is suspended on ropes





and it will sway and bounce. The vibrations that result can and will loosen the stakes. Rain may soften the ground, so check the stakes after each rain.

In summary: Check every part of the system regularly.

While you are using an air ladder, your worst enemy is wind. Wind amplifies the swaying and can make working from the ladder difficult psychologically if not physically. I would not recommend using the air ladder in high winds.

For the sake of safety, I would also recommend grounding the ladder when you aren't using it. This will also remove a dangerous attraction for the neighborhood kids.

There are no hard and fast rules for the spacing of the ladder and stakes. If you are an engineer or physicist with an interest in computing the optimum arrangement for a given height, go ahead and do so. I stood the ladder at a 45-degree angle and was careful not to let the slope of the ladder become so low that the system seemed unstable.

As far as the painting is concerned, you'll still need a sprayer, brushes, and maybe a long-handled roller to extend your reach. But don't forget that you don't have to move the ladder; you can simply rotate the dome under it. You may have to raise the ladder a little to give the shutter enough clearance, but that's a lot easier than having to pick up the ladder and move it.

Be careful—and happy painting!

Barry B. Beaman
Praesepe Observatory
6804 Alvina Road
Rockford, IL 61103

RTMC

THREE TIMES in three months I had flown to Southern California. Concern over the quality of commercial optics and desire to get that concern across drove me the first two times. This time what drove me was the cheerful prospect of seeing old friends and of spending my days and nights talking telescopes and optics.

The annual Big Bear IAPPP meeting would be a pleasant interlude, and I had thrown together a short paper to present. As the 727 banked toward the Ontario airport, to the left and below me I saw the mountains ahead, rising dark and green from the ochre desert, cupping Big Bear Lake at their center.

In March I had visited four firms in the L.A. area to hear out their concerns over declining sales and to carry to them my concern about product quality. Then in April I had returned, notebook and camera in hand, to spend a week in the factories of Meade and Celestron, poking into the nooks and crannies of their operations, talking to their employees, and satisfying myself that the telescope industry now takes seriously the challenge of delivering 1/4-wave optics.

My report on that visit is to be published in the October ASTRONOMY; you can read it there. Suffice it to say here that the vigorous efforts these companies are making to put topnotch instruments on the market impressed me. Their commitment is vital: for amateur astronomy to have a strong future, we need good instruments.

Precisely two hours after I looked from the plane window at Big Bear Lake, I pulled into the parking lot of the Thundercloud Inn, got out of the car, and walked fifteen minutes late into the IAPPP Paper Session 3 to deliver my paper, "Do-It-Yourself Image Processing Software." It's a bit weird to have a whole room full of people look up at you and say, "You're late for your paper!"

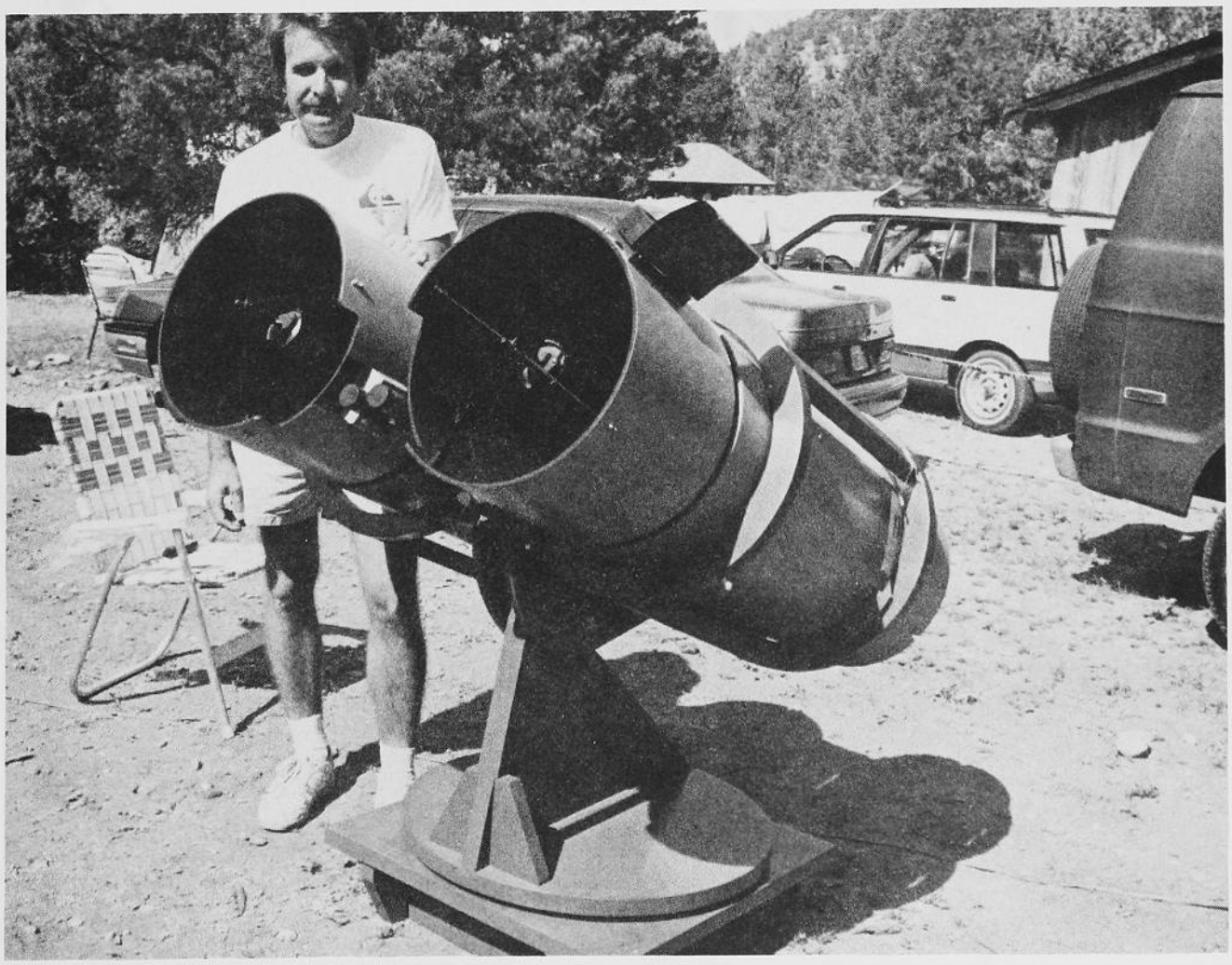
Image processing has fascinated me for years. Maybe it's because my visual world was soft and fuzzy until I got glasses at age twelve. In any event, when SBIG and SpectraSource sent their demo diskettes, I started writing a program to read and display their digital image files—and almost before I knew what had happened I was deeply immersed in the intricacies of convolution filters, logarithmic data rescaling, and unsharp masking. Because QuickBasic 4.5 is such a great medium for casual programmers like myself, my home-brew software really worked and did neat stuff. The only fly in the ointment—and the problem I laid before the assembled minds of the IAPPP crowd—was that after ten minutes of working nicely my little program would hang the computer so badly I had to switch it off.

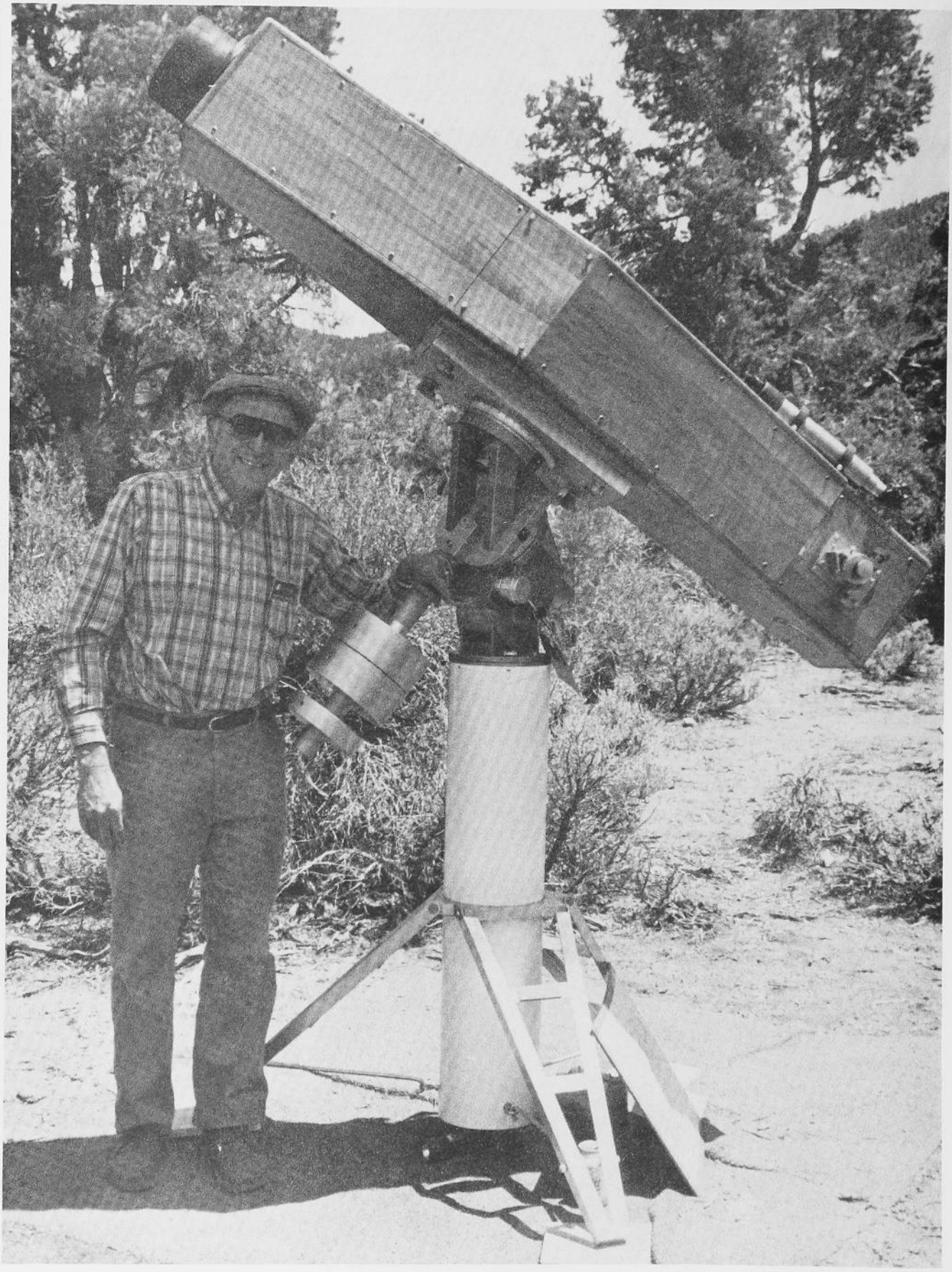
Anyway, to make a long story short, I gave the paper and afterward talked to lots of brilliant people, and even though no one had the answer, I learned enough from talking to people that I figured out what was wrong with my program on the flight home. Thanks guys, for the inspiration!

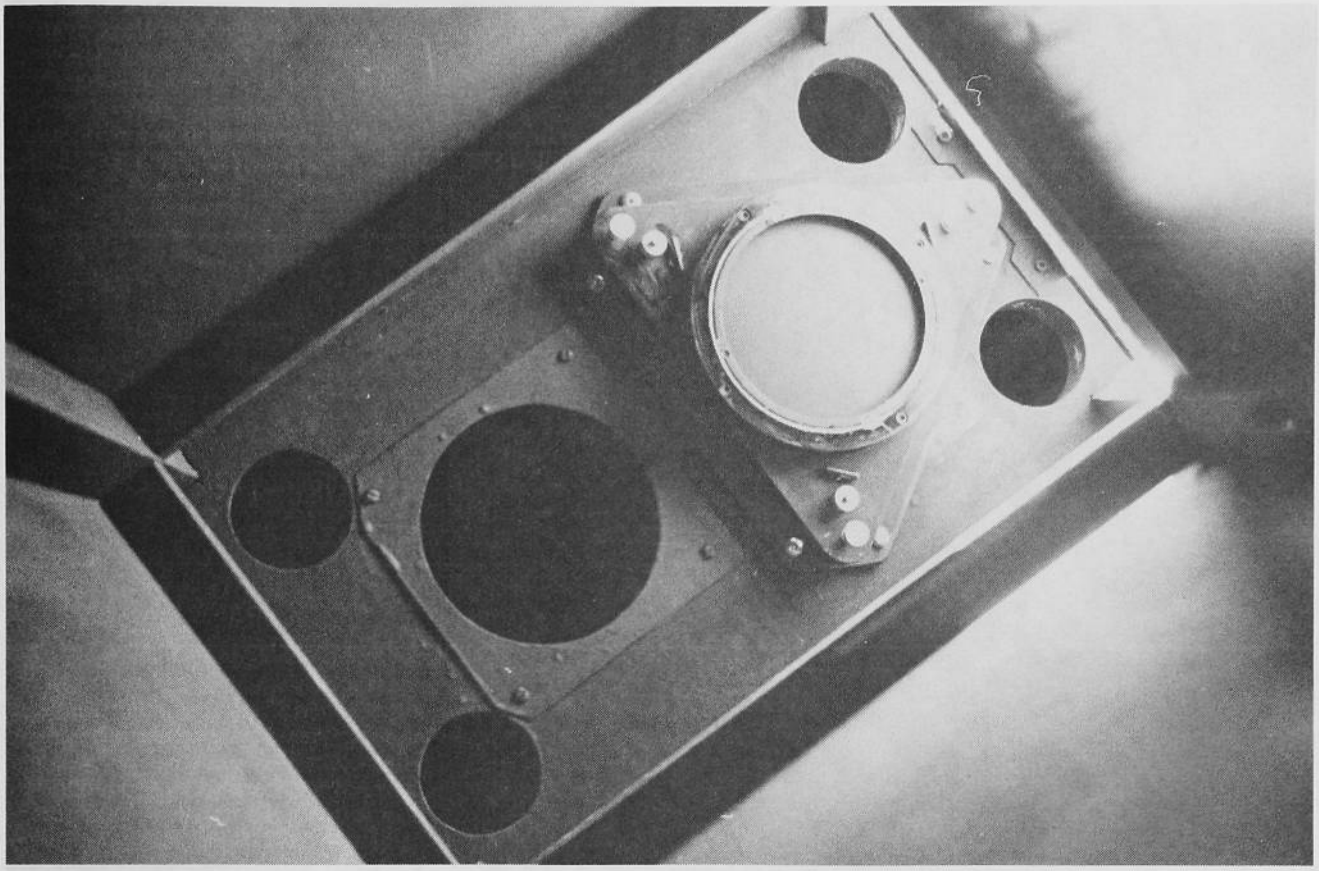
IAPPP meetings tend to be pretty intense affairs. Everybody's there to learn as much as possible and to have a good time talking shop about stuff like the latest SSP-5 or the 1990 EOA conference—all but a few. Derald Nye told us why he lives on Observatory Drive (it's a great story, Derald!) and Dave Rettig gave us the nitty-gritty details of machining APTs. Dave's machine shop is the envy of every telescope maker who knows about it, full of huge mills and monster lathes and a guy who knows how to make telescopes with it all.

The monster binocular that Rich Livitski built features twin, rotating top ends. Twin 13-inch telescopes turn on a large lazy-Susan bearing.

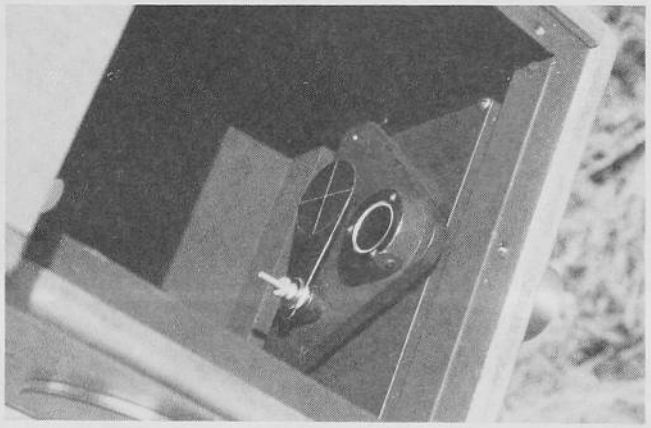
1990 (What a Year!)

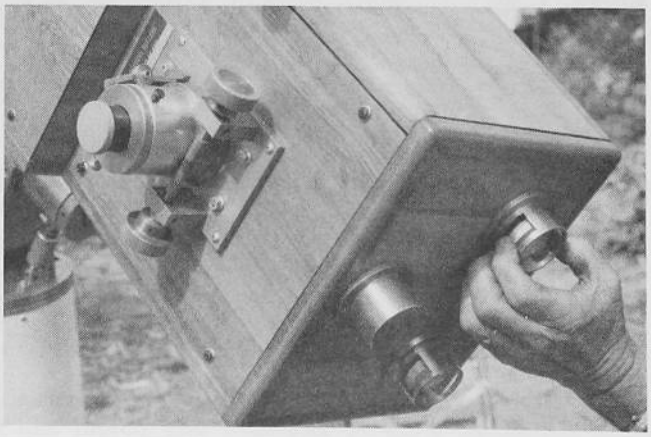






Competing with the Apochromats



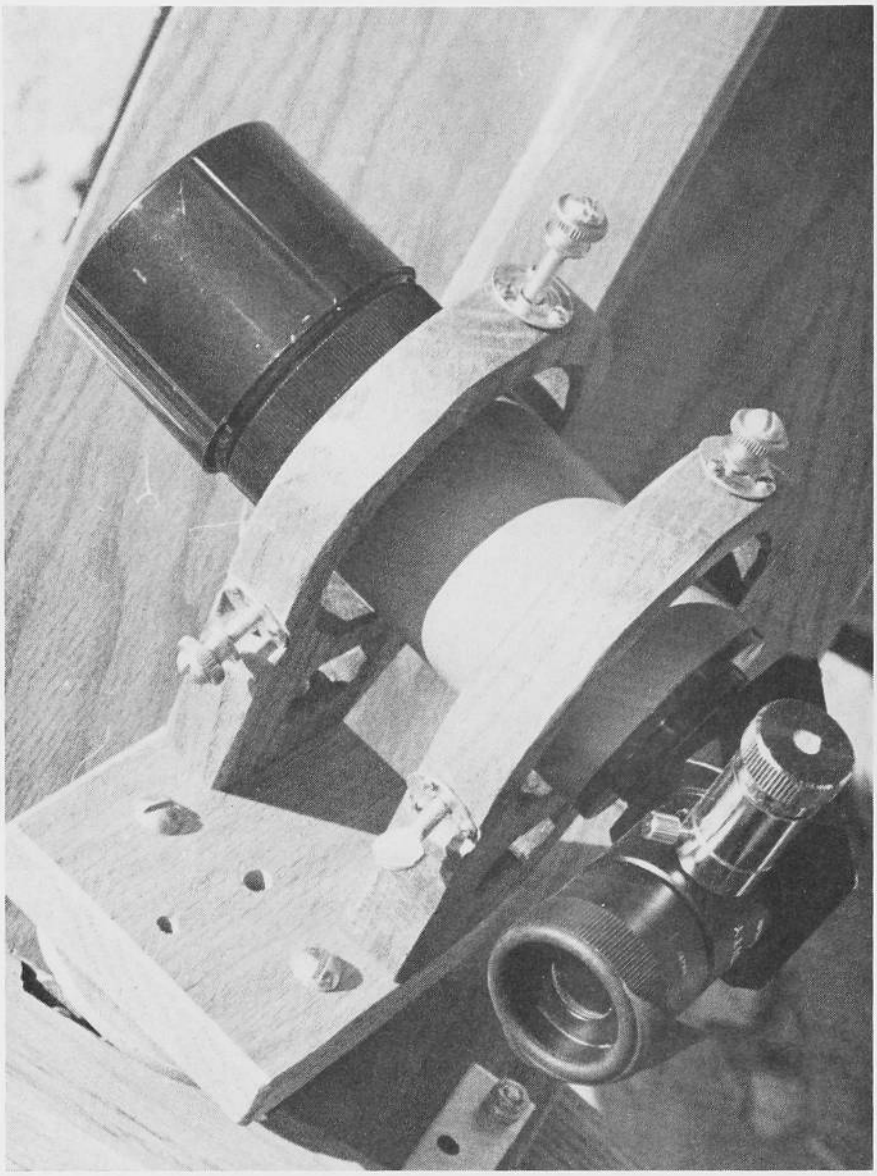


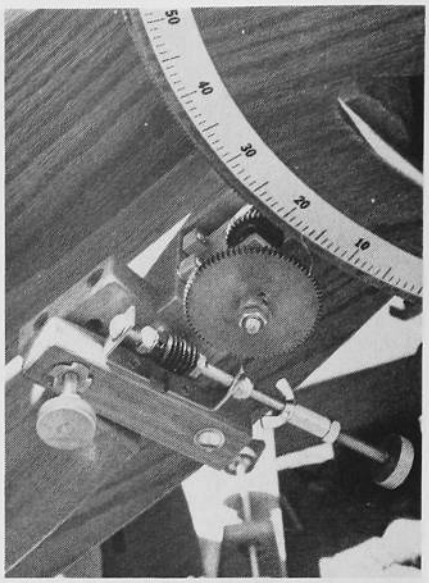
"Outstanding Design and Craftsmanship" is what the Merit Award committee said about Gerry Logan's 7-inch f/10 Schupmann refractor. Logan used Jim Daley's booklet, *Amateur Construction of Schupmann Medial Telescopes* (published by the author) as his source. Basically, the medial design employs a simple lens as its objective and a Mangin mirror to re-image the light. The Mangin relay introduces chromatic aberration equal in magnitude to the aberration of the objective, but of the opposite sign.

Logan made the tube from thin birch plywood reinforced at the corners. Roughly midway down the tube he placed a baffle (photo above) that holds the Mangin mirror. The large opening allows light from objective to reach a field mirror at the far end of the tube. This mirror is slightly tilted and images the objective on the Mangin relay mirror. The back side of the Mangin mirror holder, mounted on the baffle, is visible

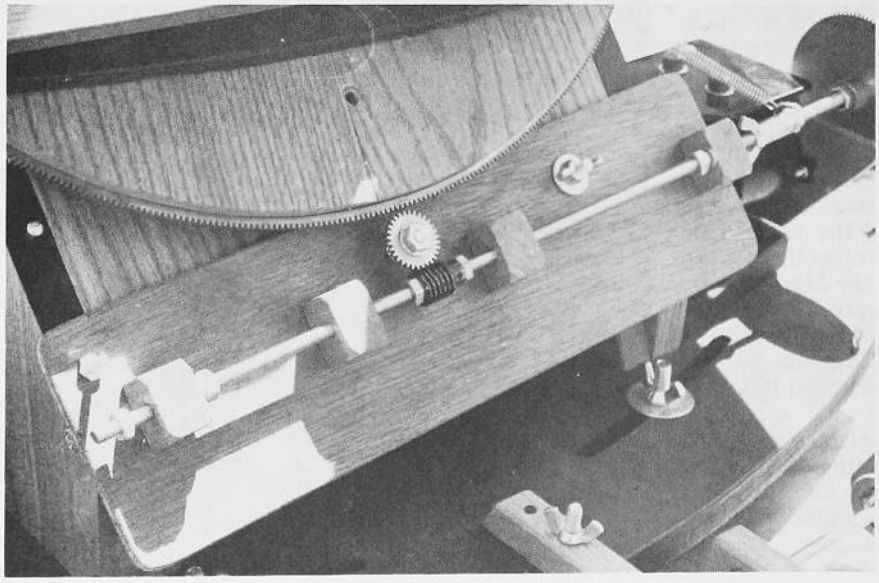
This instrument is almost perfectly color-free and is corrected axially for spherical aberration—an instrument to rival the apochromat. Logan made all the optical components himself.

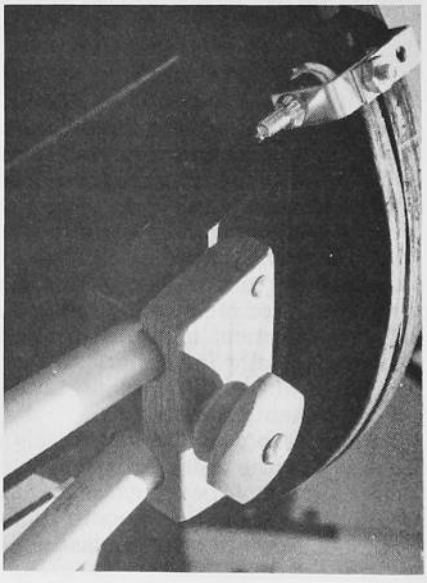
Notable also were the very nicely machined Crayford focuser and the solid equatorial mounting with large-diameter conical bearings. Molybdenum disulfide and Teflon give exquisitely smooth motion. *TM* will feature this instrument in a future issue.





The details of Mike Gibbons' 8-inch f/8 fork-mount equatorial Newtonian were executed in hardwood and metal. This is Mike's first scope.





Peel-and-stick birch veneer makes Sonotube look classy in Steve Collett's 8-inch Dobsonian. He built the focuser from a discarded C6 unit.

After dinner we adjourned to the meeting room for the annual informal drinks and snacks session, and the "guess the telescope" quiz conducted with the aid of Roger Deyoe's collection of slides taken at many observatories over the course of many years. Somehow they always look new and interesting. I'm not sure of his secret, but it may be that Roger stores the slides in an old shoe box under the computer and once a year blows the dust off for the IAPPP.

After dark, Steve MacArthur was demonstrating his Lynxx CCD camera. Steve is the main man at SpectraSource, and as it turned out, I spent a lot of time asking questions and listening to his answers during this year's RTMC. Steve took that ultimate gamble with a high-tech product—he demoed it in front of a large number of interested people. So many things could go wrong, but nothing did. The camera worked well; we found some galaxies, shot pictures of them, and stored the images on a portable PC.

The Lynxx camera is a very nice unit. It has a small chip—just 192x165 pixels—but reads 12-bit data out so there's sufficient resolution for stretching the images. (Stretching 8-bit images is tough—you run out of gray levels just when you'd most like more.) The camera head has a built-in shutter, and the PC-card version of the camera controller outputs NTSC video signals so you can see what you're getting on a video monitor. (CGA and EGA computer image displays are just about hopeless!)

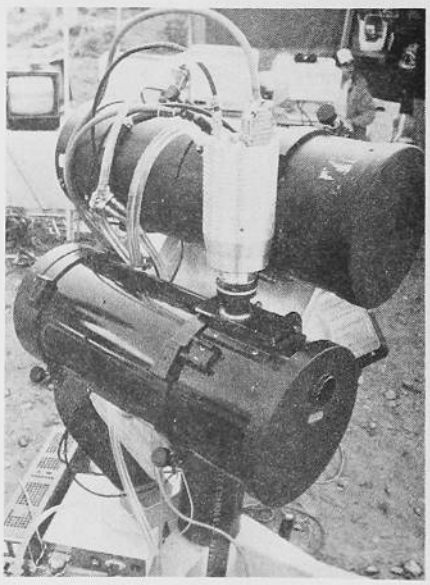
By 1 A.M. I was feeling the hour, and rather reluctantly went to bed, my brain dancing with images of digital galaxies.

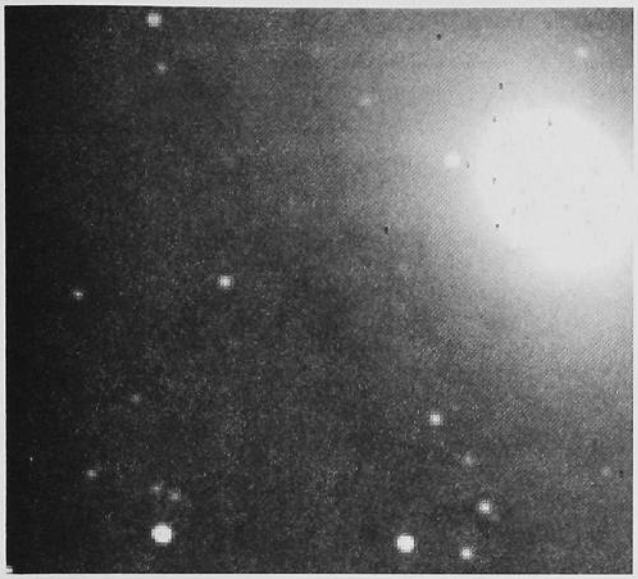
In the morning, with a sticky roll in one hand and a cup of black coffee in the other, I perched in front of Roger Deyoe's BBS computer and copied off eight disks full of public domain programs and files. Roger has, for example, a complete source code listing of AstroClock in QuickBasic. Roger's voice phone number is (714) 883-9807. Give

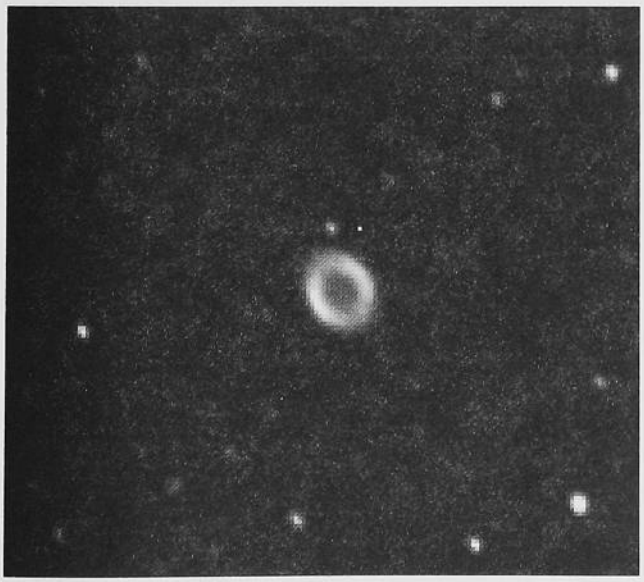
The Revolution in Astronomical Imaging

Tiny chips of doped silicon will soon change the way amateur astronomers make images of the sky. At the 1990 RTMC, at least six CCD cameras were in operation; in 1989, there had been only one. The images on these two pages come from four different cameras: the SpectraSource Lynxx-PC (M17 and M57), the Santa Barbara ST-4 (M31 and M33), the Photometrics Star I (M63 and M64 courtesy of George Fowler), and the Patterson Electronics SS-700 (M51 courtesy of Burt Patterson). In all cases, including the cover, the digital data were inserted directly into the page-makeup software we use to produce *Telescope Making*.

I think that one of the most interesting camera units (shown at right) came from Kevin Medlock and Vance Chin. The system had 512- by 486-pixel chips at the foci of a coaxially mounted 8-inch f/1.5 Schmidt camera and an 8-inch f/3 paraboloid. Such fast systems are an excellent way to beat thermal noise in the chip– the image is bright and the exposures are short. The small image scale gives a reasonably wide field. I made the Lynxx and ST-4 images with my 6-inch f/5 Newtonian. *–RLB*







Group 70 displayed a 1:10-scale model at the Epoch Instruments booth. They are building the world's largest amateur telescope.

him a call if you're into this sort of stuff; his Scientific and Technical BBS is a phenomenal resource.

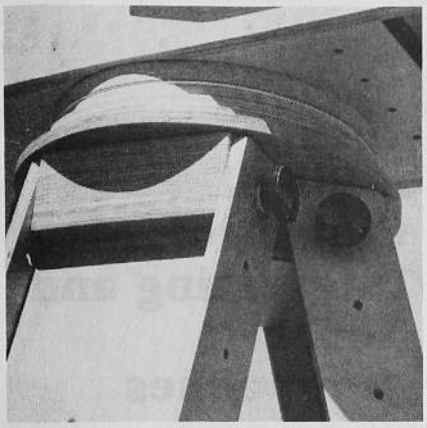
Lou Boyd remains the uncontested high guru of the APT. He's now working on a new high-precision diode photometer. As is so often the case with technical gadgets, getting quick and dirty readings with a diode photometer is easy, but squeezing the last ounce of precision out of a device is a pain. Lou described all the second-order effects that he must allow for to get millimagnitude accuracy. Clearly the payoff will be large when a tireless APT can just bang away at some star with spots or other chromospheric abnormalities and record a long time series of precise rotation curves. Last time I spoke with Doug Hall, he had found evidence of migrating spot groups in RS CVn data, and here's Lou developing the means for making more and better light curves of these very stars.

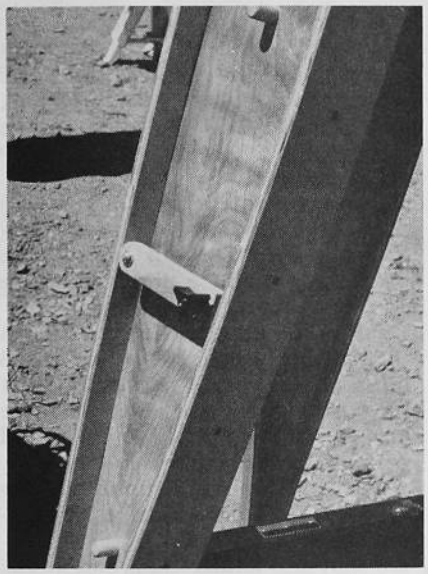
Noon approached and we posed for a group photo—never a serious event at IAPPP meetings—and the meeting was over. I lugged my stuff across the road and stuffed it into my rental car, now baking in the sun not ten yards from where we had been imaging galaxies the night before—an amazing contrast. I opened the door, climbed in, and buzzed off to the RTMC.

———

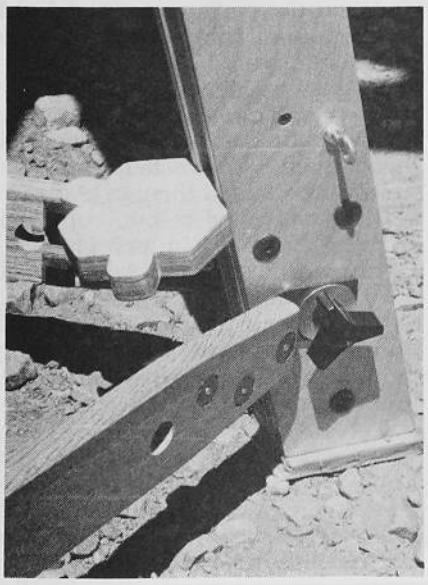
Riverside this year was dedicated to the memory of Bob Cox. Among Bob's enduring legacies are the Merit Awards. Merit Awards are not prizes in a contest, but simple recognition of achievement. Understanding the need to draw attention to new ideas, Bob asked Cliff Holmes to consider the advantages of doing away with competitive prizes and replacing them with the system of merit awards of equal rank that Riverside still has.

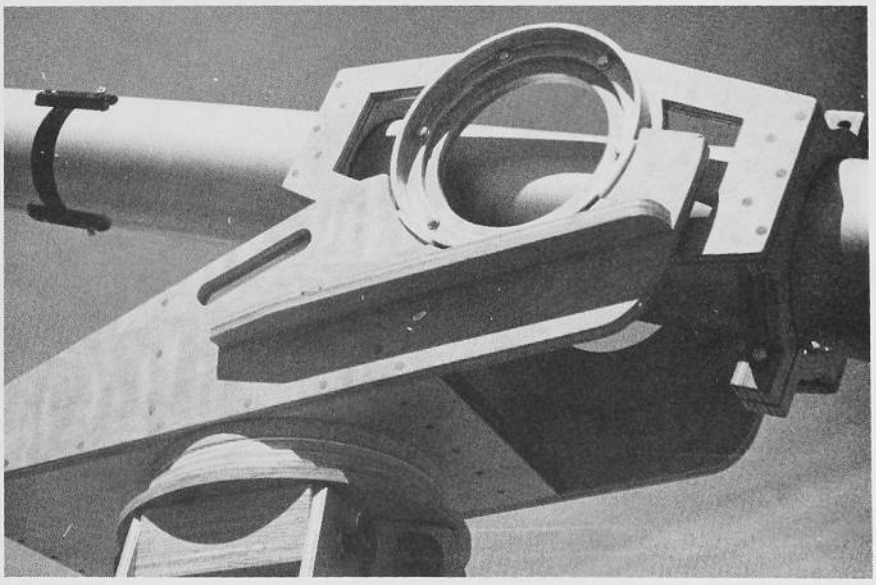
Once again this year, Randy Wilcox had asked me to serve on the Merit Awards committee. This entails a lot of work, especially finding and examining telescopes spread all over the ground of Camp

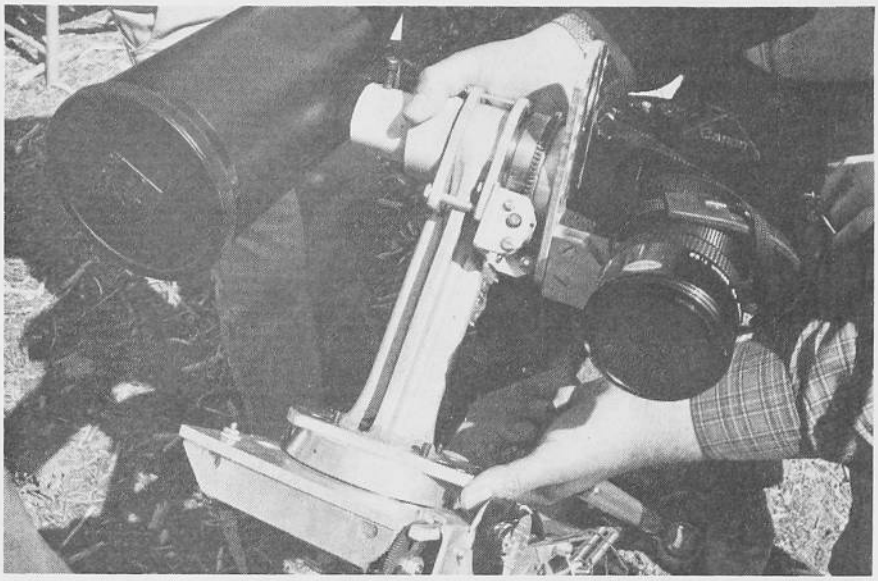


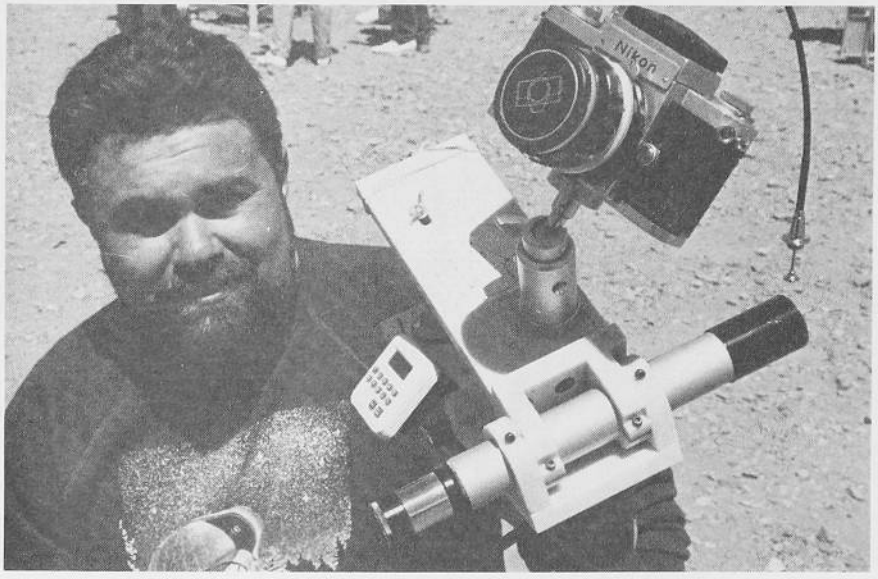


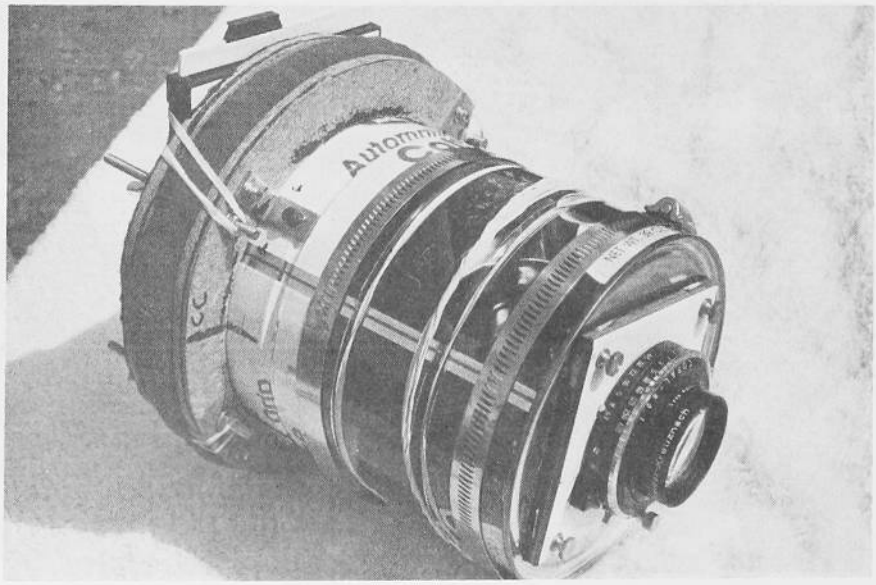
Bill and Deb Ball mounted their 6-inch f/12 Christen super-planetary refractor on this free-moving, birch-plywood alt-azimuth mounting.











A Small Collection of Interesting and Novel Approaches

His single-arm fork mount lets Carter Roberts guide and shoot with lenses up to 400mm focal length. To balance the system, Roberts can bolt the axis to the polar drive at several different lateral positions.

Polar alignment is difficult with conventional tangent drive platforms. Gene Dietzen solved the problem by using a finder telescope as the mechanical polar axis!

Put a Schneider Xenar lens on the front of a coffee can and a 4x5 film holder on the back—what have you got? Lance Peck's coffee can camera is simple to build and performs well in comet photography .

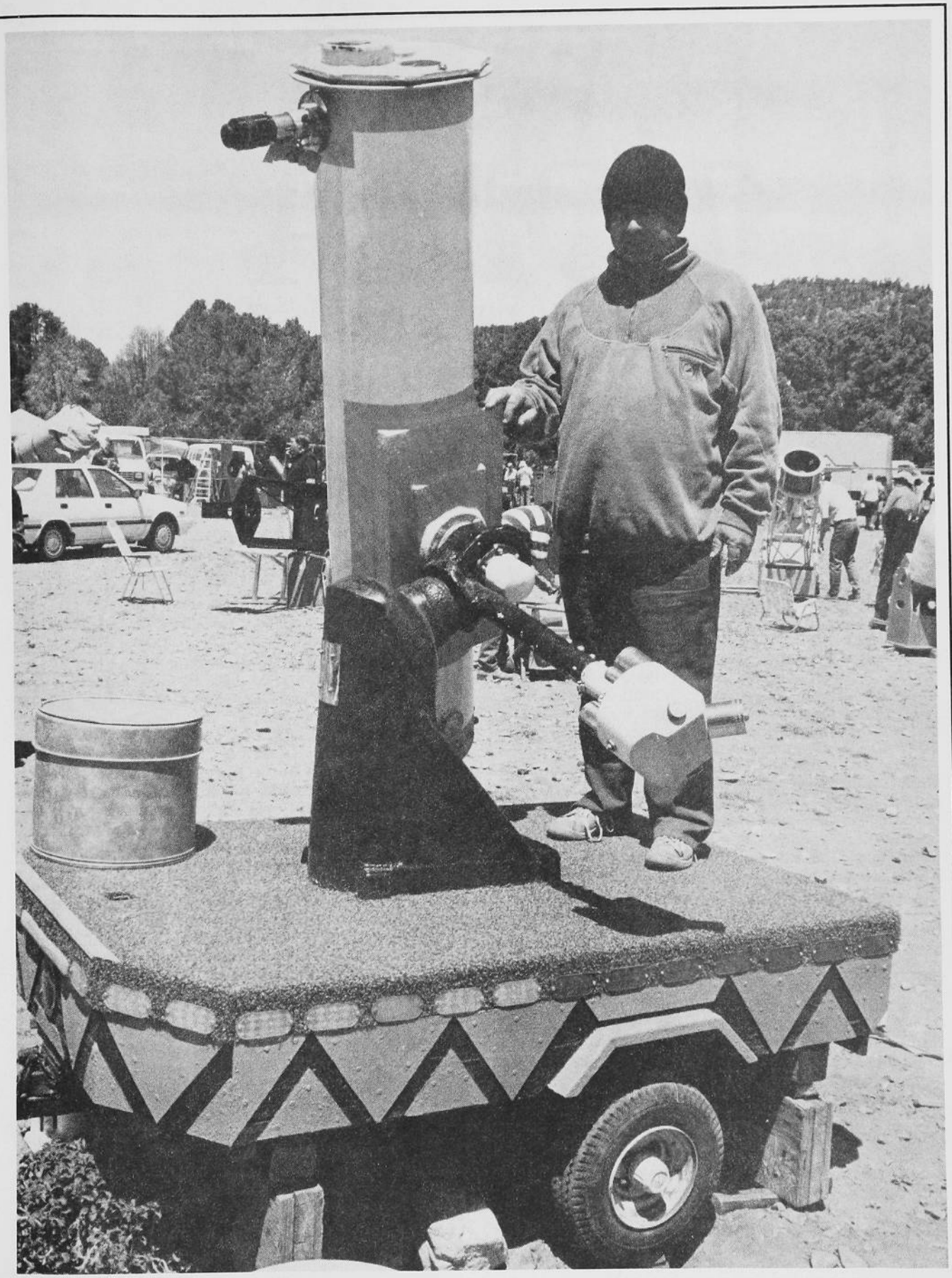
David Shipman mounted his 12.5-inch f/5 closed-tube Newtonian on a super-solid trailer. Readers may remember Shipman as the man who showed the 29-inch f/4.5 Dobsonian several years back.

Every component of this massive mount is wonderfully over-built. Shipman welded truck axles together for the basic structure. He finished the parts with paint laced with ground walnut shells, for an unusual textured effect.

Socket wrenches two to four inches in diameter supplement the main counterweight. Shipman had filled them with washers for more weight and bolted them in place.

The trailer bed is built up from sixteen layers of 3/4-inch plywood, a 12-inch thickness of wood. When I joined Shipman on the platform, it felt extremely solid, and I could jump up and down without feeling any shake. The total weight of the trailer is over a ton.

The front of the telescope has a plate glass window. "Closing the tube cuts down tube currents greatly," says Shipman. The optical tube is completely sealed, and the air inside is dried with silica gel.



TOMA

an idea whose time has arrived

With more enthusiasm than I've seen before, representatives from a dozen or so telescope companies convened in the common room of Coombs Lodge at Camp Oakes on the last day of the 1990 RTMC, Monday, May 23. It was an informal gathering in some repsects—we lit a fire in the fireplace and draped ourselves on the ragged sofas and beat-up easy chairs while the last of the Camp Oakes lifeguards grabbed their belongings and beat a hasty retreat. Outside it was storming—snow and hail turning to rain—as inside Paul Jones called the meeting to order.

After a short discussion of the by-laws, talk turned to the purpose of the organization, a subject that could have been quite touchy. Within an hour, somewhat to my surprise, the group reached a consensus, nicely capsulized, if I remember correctly, by Al Nagler: "TOMA means you can trust their optics."

In broad terms, the charter and principles of TOMA would be 1) to promote uniform and high standards of optical quality, 2) to promote fair and reasonable optical specifications, 3) to promote fair and reasonable claims in advertising, 4) to promote public awareness of the telescope industry, 5) to build public confidence in the telescope industry, 6) to teach the public about the telescope industry.

With the purpose nailed down, Paul asked for volunteers for three committees that will do the work of TOMA. These are an optical standards committee, a public relations committee, and a research and development committee. Volunteering for the first (optical standards) were Terry Ostahowski of Meade, Tom Johnson of Celestron, and Roger Sinnot from *S&T*. Named to the second (public relations) were Al Nagler from TeleVue, Gary McDonald from Parkes, Wayne Johnson from the OCA, and myself. (Wayne characterised the OCA's role as that of "an interested party.") On the third (R&D) were Paul Jones from Star and Peter Ceravolo from *TM*.

Paul Jones will serve as the interim president until nominations and elections are held next year. The membership fee is $50, and membership will be open to companies that will uphold the standards of TOMA.

I was pleased with how well the meeting went. If nothing else results from it, I think that some good will come because many of the key players in the telescope industry finally met for the first time.

The industry-wide crash that followed the apparition of Halley's comet did little to encourage manufacturers to put out a quality product—and the fruits of that laxity came home to roost in 1990, when demand for telescopes sank to a new low. The formation of TOMA could mark the beginning of new era of prosperity for the telescope industry.

—Richard Berry

In the past most amateur astromoners took advertised claims of optical quality at face value because there was no easy way to verify them. In the light of product reviews published in the last eighteeen months, many amateurs now insist on verification of optical quality before they purchase a product.

What TOMA can do: In my opinion, exaggerated or misleading claims in advertising for optical products have played a major role in undermining consumer confidence. I believe that TOMA can do the most good for the industry by setting standards for the advertising and marketing of optics. From discussions I have had with key people in several firms, I've come to realize that optical firms often feel that rather than basing quality claims in their ad copy on the quality of the product, they must instead "one-up" the claims their competitors make. The result is that optical components and systems are sold on the basis of exaggerated claims—while the consumer has been educated to expect the quality promised in the ad copy.

As a result, I believe that amateur astronomers have become desensitized to the difficulty and expense of producing 1/10-wave or better optical components and systems on a production basis, especially in systems as complex as the Schmidt-Cassegrain. Many amateur astronomers now observe with 1/2-wave optics and greatly enjoy the celestial veiws such optics deliver. TOMA can re-educate the consumer to understand that near-perfect optics (i.e., 1/10-wave or better) are not only unnecessary but also too expensive for most observers.

Of course, there will always be a demand for high-quality optics and systems, and with experience,

What a soggy-looking bunch! — but it was raining and/or snowing at the time. This photo shows most of attendees of the third TOMA meeting, immediately following the meeting, while we were all still a bit groggy.

beginners will learn what they can expect from the different quality levels offered by manufacturers.

The test methods used in the large-scale production of optics must often be subjective and, in addition, are not sufficiently sensitive to reveal defects on the order of 1/20-wave. The simple Foucault test and Ronchi tests are not especially sensitive to serious flaws like astigmatism and do not readily give quantifiable measures of figure error, especially when the errors are slight.

If every company that became a member of TOMA would make quantifiable advertising claims (such as "1/10-wave") only when the claim was based on quantitative tests such as those made with interferometers, and if they backed their claim with an interferogram delivered with the optics, consumer confidence in optical quality would be restored. Firms that did not advertise quantifiable standards would, as I am sure they always have, deliver the best quality possible for the price.

What TOMA cannot do: While it is easy for an organisation such as TOMA to monitor marketing practises, it is impossible to police optical quality. TOMA can only guarantee that member firms will not misrepresent their products in advertising. TOMA cannot and should not promise consumers that member firms manufacture a given quality because there is no way for TOMA to check every optic.

Only when amateur astronomers know what they are getting for their dollar will they buy with confidence. In such a market, manufacturers offering inexpensive optics of reasonable quality (1/2-wave or so) would compete on an equal footing with those guaranteeing 1/10-wave or better (and therefore relatively expensive) optics, with documented proof of quality.

I have tested many telescopes and components. Most of the people I have talked to understand that a less-than-optimum product can be an excellent value for the dollar spent. Those people get really upset when they feel they have been misled by exaggerated claims of quality.

TOMA can help the telescope industry only if enough companies participate. I appeal to readers of *Telescope Making* to write to your favorite optics manufacturers and urge them to join TOMA. Everyone will benefit when the member companies of TOMA champion honest advertising and fair competition.

— Peter Ceravolo

Hefting a Hextek eggcrate mirror blank is master optician Bob Goff. Goff perfected Celestron's corrector-making process back in the 70s.

Oakes. And although each year the rules on where award candidates can put their telescopes get a little tighter, the telescopes are still pretty spread out. Anyway, it's nice for me because I get to look at every telescope entered, something I would try to do anyway.

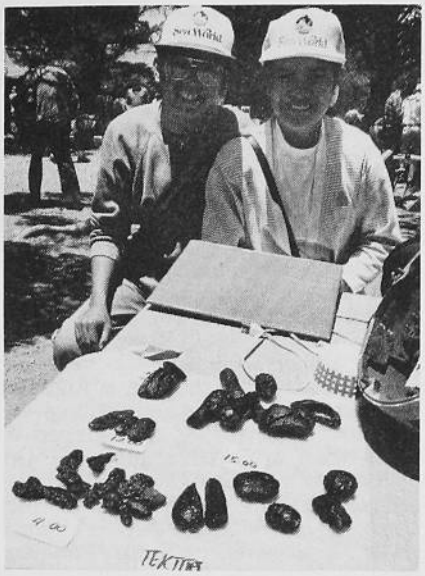
So that's what I did Saturday—chase down telescopes. Sunday morning the Awards Committee met, and by lunchtime we'd hashed out which dozen or so of the thirty to forty entrants enriched our hobby in some particular way.

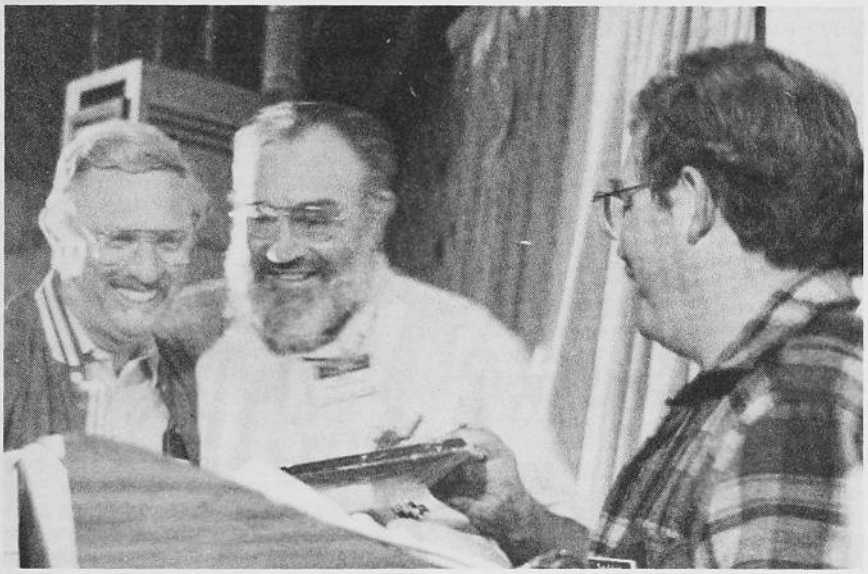
The rules are pretty loose; one test I apply is whether I would say to a friend, "Hey, take a look at that [whatever] half-way down Telescope Alley. There's some nice stuff in it!" If I would recommend that a friend go take a look, there's some merit in that telescope.

We (i.e., the committee) presented the awards Sunday evening. Chairperson Randy Wilcox thanked the entrants "for the opportunity you give everyone who attends RTMC to learn from your experience and the energy you put into teaching those who see your telescope on display."

Arnie Richards presented two awards, the first one to Mike Spooner for a home-built 6-inch Cassegrain. The mount had home-cast fiberglass gears cut with a length of all-thread with a spiral flute. Arnie then cited the smooth rotation and fine crafsmanship in Jim Brunkella's 16-inch f/4.5 well-crafted Dobsonian.

Twenty-one year RTMC veteran Paul Zurakowski pointed out the features that impressed him in Vance Tyree's 12.5-inch Dobsonian, especially its portability, and in Steve Collett's beautifully birch-finished 8-inch f/4.5 Dobsonian. Steve applied peel-and-stick birch veneer to a Sonotube. Paul also cited Ray Magdziarz's 10-inch f/3.9 Dobsonian mounted on a d'Autumn platform. Ray made the mirror and adapted bits and pieces of toy race cars and a speedometer cable for this portable, clock-driven equatorial platform. "Ray is a tele-





Grinning broadly, Dick Buchroeder (left) receives the annual Clifford W. Holmes Award from Bob Schalck (right) and Ashley McDermott.

scope maker of the old school," said Paul. "He makes pretty much all the parts himself."

Rick Schaffer named Ray Coutchie's 6-inch f/5 and f/10 convertible Newtonian as meritorious. The square wood tube has the f/10 mirror at the bottom, and halfway up is a shelf that Ray's f/5 mirror slides into. In awarding Ricj Livitski's 13-inch binocular an honorable mention, Rick warned, "There's method in his madness." Mounted on a massive lazy Susan, this instrument features rotating upper ends and, Rick said, "It even works pretty well!"

Rick has known David Shipman for a long time, and he took obvious pleasure in describing David's 12-inch sealed-tube Newtonian with front wheel bearing from trucks.

My turn was next. In every way 16-year-old Jason Brown's 10-inch f/5.6 Dob is a worthy effort as a first telescope. Jason's use of a plastic toilet flush valve for his focuser shows how common materials can serve in a fine telescope.

I really liked the look and feel of Carter Robert's single-arm fork camera mounting. Carter's dislike of counterweights led him to rethink the polar axis. Bill and Deb Ball's 6-inch f/12 alt-az refractor had obvious appeal for me; it's nice to see variations and improvements on a basic design. This telescope moved as smoothly as any I've ever seen, too.

Bob Schalck, "the youngest of the old group who've been coming to RTMC for 20 years," presented awards to Steve Ambrose and Mary Henderson for their bias-plied wood-veneer telescope tube and to Mike Gibbons for his intricate 8-inch f/8 equatorial Newtonian. "He's got an awful lot of stuff on there," said Bob.

For its combination of optics and fine craftsmanship, Bob cited Gerry Logan's 7-inch f/10 Schupmann, a singlet lens with a Mangin corrector. "As an optical designer," Bob said,"I love systems like this one."

Randy Wilcox gave the final merit award for the evening to Barry Thompson and the fifth and sixth grade students of the Myers Elementary School for their Sun telescopes. Using discarded binoculars mounted in big, Dobsonian-style boxes to project the solar image, the kids had a safe and dependable way to view sunspots.

Bob Schalck presented the Cliff W. Holmes Award to Dick Buchroeder. Given annually by Astronomy for America, the Holmes award recognizes leaders in amateur astronomy. Over the years, Dick, a professional optical designer, has examined dozens of new optical designs for amateurs. "I bend light rays for a living," Bob said as he placed the plaque in Dick's hand, "and you've been helping us ray-benders come up with new ideas for a long time." *TM* readers are quite familiar with Buchroeder's influence; in this issue you'll even find spot diagrams Dick did of a new optical design. Mr. Buchroeder, many thanks for your help!

– – –

When all the ceremonies were over, all the awards presented, all the door prizes given away, and the hall had cleared out, I thought it was time to go off and get some sleep. No such luck—Al Dyer, Peter Ceravolo, and I spent the next three hours "talking optics" with Al Nagler, Rocky Cimarusti (Celestron), and Terry Ostahowski (Meade). Everybody was keyed up for the TOMA meeting the next morning (see pages 40 and 41) and we were full of chatter. At least it was a cloudy night!

—Richard Berry

Letters

Making the Ross Null Lens

Dear Peter/ My belated thanks for the calculations and encouragement. And a hearty congratulations for taking the torch passed by Bob Cox. Now on to progress on my Ross Null lens.

Making the test lens has been no big deal. While I have been sidetracked from mirror and lens making lately, I have managed to rough a 4-inch-diameter, 0.55-inch-thick piece of Schott grade-A BK-7 to a radius of curvature of 10 inches. I did it by hand, using a 4-inch pyrex blank as a tool. The edged crown blank cost $25.00 from United Lens, and the Pyrex blanks are $8.75 from the same source. I was surprised at the small amount of wedge (0.005 inches) at the conclusion of roughing with #80. It will be no problem to control the wedge, and I will do so even if it is unnecessary. I was also surprised that I lost very little center thickness (0.035 inches).

I will figure the tool to a sphere to be used as a test plate for R1. I have a 6-inch flat for testing R2, the flat side. I will cast cement pitch bases for polishing T1 and R2. At this point I anticipate no unsolvable problems. I have some smooth paraboloids, polished and figured with rouge, that should reveal any zonal imperfections that interference testing with my Argon beamsplitter might not disclose.

I believe an amateur will be better off making the Ross lens than having to agonize whether a commercial lens has been properly made. For $34.00 worth of glass, anyone can make an excellent lens. Some will say that the time factor is high, but what the hell, this is a hobby. As Mark Twain said, a hobby is nothing more than a device to murder time.

I realize that no amateur technique can match a Zygo or autocollimation with a large flat. Every test available has flaws and is a compromise. But I would rather put my faith in someone who has tried both, Dall Null and the Ross Null, than someone who has derived his information from books.

Any progress on the BASIC program for calculating the separations, etc.?

Gil Stacy
425 E. 50th Street
Savannah, GA 31405

Thanks for your Help

Dear Tom Clark/ So there I was, with my nine-month-old Odyssey II, the first thrill of bright galaxies, easy planetaries and globular clusters like piles of sugar beginning to fade a little as the triangular, never-quite-focussed star images reminded me that the telescope wasn't really working as it should. I'd gone the easy route already: new spider, new focusser, and, oh sure, I could stop it down to 6.75-inches and see beautiful star images and split doubles and see unbelievable detail on Jupiter. But if I'd wanted a 6-inch telescope I wouldn't have bought a 17.5...

And then I read your article in TM39 and began sketching cheap, one-afternoon mirror cells to replace the crude taped-in "cell" which comes standard on the big Coulter Dob. And two weeks ago a friend of mine and I built one of those one-day wonders (bent brass clips, lx2-inch fir strips, wood screws, ball bearings, cork pads, silicon adhesive—a veritable flurry of telescope making, a fugue of designing and cutting and drilling).

I think a mirror elf has slipped in since then and either refigured the primary or put new glass in the telescope: It cannot be the same mirror. Galaxies are crisper. Jupiter shows good detail even without stopping down and shows much better detail than it did with a mask, of course. M13, M4, several of the little NGC clusters are really piles of sugar; I can see one quarter to half a magnitude fainter now that all the light is getting packed into a smaller blur circle; and doubles I never attempted at full aperture for fear of being reminded how awful the mirror was are now risply split.

Thanks for the excellent advice! Now I get to look at all of last year's spectacles again—it's not every day you get a new 17.5-inch telescope for $10 in glue, brass and screws.

David Cortner
203 Degggod Lane
Johnson City, TN 37604

Optical Foes

Dear Richard/ This past October I suddenly rediscovered astronomy as a hobby after being sidetracked for many years. When I was 10 years old, I became transfixed at the sight of Saturn through a neighbor's small refractor; it was a thrill to experience the same excitement again. I'm in the process of collecting the remaining past issues of *TM* and struggling to understand the mathematics in Rutten and Valrooij's *Telescope Optics*.

I am now in the military and stationed in the Mohave Desert where the skies are relatively free of light pollution. My first project (see photos) is a 3-inch f/11 folded refractor, built primarily for my own education. Daytime views were beautiful but star and planet images showed defects (I pulled the telescope out of the vehicle at night, during lulls in our simulated battles against our "Russian" foes).

Anyhow, this is how I learned about "pinched" optics. However, I'm still not sure to what extent the secondary flats or tilt of the objective contribute to the faint ghost images and mild astigmatism. I'm hoping to find an article that can quantify the expected

aberrations and show how to avoid them.

My next project will be an 8-inch TCT with optics by Dan McConaughy. I'm hoping all goes well with it. By the way, thanks for a super magazine!

Robert R. Guion
108 Langford Lake #102
Fort Irwin, CA 92310

Plea for Optical "Fab"

Dear Mr. Berry/ You are to be congratulated and thanked for the fine display and write-up on my long-time friend, Bob Cox. As a member of the Hayden Planetarium Optical Division in the late 30's, I worked with Bob and got to know him well.

Bob was unfailingly helpful to the telescope-making fraternity; he was truly devoted to this cause. I have subscribed to your valuable magazine since the beginning, and I admire the care with which you and Bob have created and monitored the quality of each issue.

At one time or another, I have been a member of several well-known "telescope making" clubs in eastern Massachusetts. The quotations are because there was absolutely no telescope making going on at all! Commercially available optics seem to have extinguished any interest in the making process. Therefore I would like to ask you as editor whether there is any way you could lead the fraternity back to an interest in optical fabrication? *Telescope Making* contains splendid articles on this subject, but so many border on advanced techniques. Would there be any room for an occasional series on more elementary mirror- and lens making in the grand tradition?

It may be that you have looked into all this. On the other hand, I cannot help but believe that there are many potential enthusiasts who would welcome your practical encouragement.

Marshall B. Nunlist
288 Mirick Road
Princeton, NJ 01541

—We are stepping up the number of stories about optical fabrication because TM's readers are showing an in-

The 23rd Psalm for the Refractor

The Refractor is my Telescope; I shall not want no other. It maketh me see sharp images of the Planets; it restoreth my faith in Optics; it leadeth me to abundance of Planetary Detail. Yea, though I walk through the Valley of the Schmidt-Cass and the Dumb Dob, I shall fear no telescope, for the Achromat and the Apochromat are with me, and comfort me. Thou preparest a path before me in the presence of High Resolution; Thou anointest my eye with Crisp Images and High Contrast. The images of others pale before Thee and Thou knowest no equal. Surely Thou shalt display the true beauty of the Planets to my frail eyes for all the days of my life, and I shall glory in the superior Definition of Thy images forever.

creased interest in fabing optics and in testing. Peter is a professional optician and with his help and continued interest from the readership, a series on mirror-and lens-making is a distinct possibility.

Autocollimate!

Dear Richard/ Autocollimation testing of optics using an optical flat is a simple, convenient, and versatile method. Unfortunately, there seems to be a general impression that a flat useful for precision testing must itself be as precise as the optics to be tested. Common sense would suggest that to test a mirror or a lens to 1/20-wave, the optical flat used for the test must itself be flat to 1/20-wave.

However, this is totally untrue. Flats that are convex or concave by a hundred waves or more, can give nulls precise to better than 1/50-wave. I realize that this seems incredible, and I enclose copies of the references cited below so you can verify the facts for yourself before publishing this letter.

The formula that relates the accuracy of a flat used in an autocollimation test to the accuracy of the null observed in the test is given by C.R. Burch in "Tolerances Permissible in Flats for Autocollimation Tests" in the Monthly Notices of the Royal Astronomical Society 98, 670 (1938), and by D. Malacara in *Optical Shop Testing*, published by John Wiley & Sons, (New York) in1978:

Error of flat = ±128 (Error of null)(F/D)^2

Here, F/D is the focal ratio of the mirror or lens under test. Suppose that we are testing an f/4.5 paraboloid and that we want a null accurate to 1/25-wave. Then the allowable error in the flat used for autocollimation is 128 X (4.5 X 4.5 = 20.25) X 1/25, or ±104 waves. Since the allowable error increases as the square of the focal ratio, testing a f/15 refractor objective to an accuracy of 1/25 wave allows an error in the flat of ±1150 waves. A wavelength of green light is about .02 thousandths of an inch, so a "flat" that is 1150 waves from true flatness will be concave or convex by more than 20 thousandths of an inch, hardly a precision optic!

How can a flat this bad give a null accurate to 1/25-wave? I will not attempt a quick and easy explanation. Burch gives a complicated derivation of the formula based on offense against the sine condition, and I don't pretend to understand his mathematics. I am merely reporting facts that seem to have been known to professional opticians for at least fifty years. I only recently came across this information, and I imagine that many readers will be as surprised as I was at how bad a flat can be and still give a precise autocollimation test.

There are scattered hints in the literature commonly available to amateurs that flats used for autocollimation tests can be less than perfect. For example, Texereau (p. 164, second English-language edition) says that "slight curvature is of no consequence in an autocollimator setup. It means merely that the source would appear to be at a large finite distance rather than an infinite distance." This is reminiscent of the old rule of thumb that an artificial star used for testing should be at least 20 times the focal length away from the objective under test. The formula given here makes these hints far more meaningful by giving the actual tolerances for a test flat, which in fact are not slight, but huge.

Optical flats with "a few fringes of power" (two fringes equal one wavelength, and "power" means concavity) are relatively inexpensive in the surplus optics market. I recently saw a 12-inch Pyrex flat, stated to be 1/4 wave over any 6-inch area, advertised for $300, and smaller aluminized flats with a wave or two of error are sold for even less. Such flats are not suitable for image-forming applications, but they can give an autocollimation null test that is extremely accurate indeed.

In the good old days of a few decades ago, amateurs were not afraid to make their own optical flats. There are many articles on this subject in the ATM series edited by Ingalls. It is only recently that amateur opticians seem to have gotten scared of flats. What's there to be scared of? As somebody remarked years ago, a flat is simply a spherical mirror of infinite radius. Does that sound so hard to make? There has also been a lot of fuss about testing flats. Only a few months ago, Ed Jones took the mystery out of that subject in an article in the July, 1990 *S&T*. Ed describes how to test flats (diagonals too!) by using interference with the surface of a small container of water. The accuracy of this test for a 12-inch flat is 1/500-wave, which is simply the curvature on the surface of the water matching the curvature of the earth.

When I compare the simplicity of the autocollimation null test with the fuss and uncertainty of zonal Foucault measurements with the masks and the pinstick and the guessing at whether a zone has darkened evenly or not, the null test wins every time. And now that we know about the easy tolerances for flats used in autocollimation null testing, I hope that opticians writing articles for *Telescope Making* will not consider this test technique too exotic for their amateur audience and will share their knowledge with us.

Herbert Highstone
P.O. Box 249
Monte Rio, CA 95462

Anyone for a Solano?

Dear Richard/ I'm writing in hopes of locating someone who has successfully completed a three-mirror Solano. I have questions about scaling his three mirror 8-inch f/15 design to 10-inches and especially about collimation.

Two years ago I successfully completed a 10-inch Buchroeder Schiefspiegler. It's a great instrument, but I find the eyepiece position difficult for objects lower than 30 degrees from the horizon. The Solano's eyepiece is in a better position.

Charles Jacobson
1823 Highland Dr.
Puyallup, WA 98372

Another 23rd Psalm

Dear Richard/ There is no way that I can let "The 23rd Psalm of the Astronomer," pass unanswered. I feel that the Refractor, the One True Telescope, recieved rather short shrift in the David Knowlton Version. Therefore, I have taken it upon myself, as my solemn duty, to come to the rescue of Refractor Lovers everywhere and restructured the 23rd Psalm in honor of the Refractor, enclosed herewith.

Ronald C. Tanguay
Periwinkle Park
306 Reynolds Drive
Saugus, MA 01906

———

Telescope Making's
Blue Pages

Telescope Making Supplies for Amateur Astronomers

ALUMINIZING & COATING

Evaporated Metal Films ..... (607) 272-3320
701 Spencer Road
Ithaca, NY 14850

P.A.P. Coating Services..... (714) 535-4460
1112 Chateau Ave.
Anaheim, CA 92802

MIRROR MAKING KITS

6"	8"	10"	12.5"	16"
$53.75	$93.75	$199.50	$329.00	$490.75

All kits shipped postpaid in continental states. California residents add 6.25% sales tax.

Kits include all necessary grinding & polishing compounds, materials to make and temper your own pitch laps, fine annealed PYREX mirror blank, and our own unique plate glass tool (tool is channeled for faster grinding action). All compounds are in reuseable, resealable plastic bottles.

We also provide:

* *grinding abrasives*
* *polishing compounds*
* *rosin/pitch/beeswax*
* *PYREX mirror blanks-up to 40" dia.*
* *lens blanks*
* *we can "custom" create a kit for you*
* *discounts on bulk orders*

We cater exclusively to the "Amateur Telescope Maker". Call or write for price list and additional information.

PALOMAR OPTICAL SUPPLY
P.O. Box 1310
Wildomar, CA 92395
(714) 678-5393

BOOKS/PAMPHLETS/INFORMATION

Cambridge Univ. Press..... (800) 872-7423
In New York (800) 227-0247
40 W. 20th St., New York, NY 10011

Optica b/c Co. ..... (415) 530-1234
4100 MacArthur Blvd.
Oakland, CA 94619

DRIVE ELECTRONICS

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

EYEPIECES

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

Meade Instruments Corp ..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

Parks Optical ..... (805) 522-6722
270 Easy St.
Simi Valley, CA 93065

Sky Designs ..... (817) 656-4326
4100 Felps Dr., Bldg. C
Colleyville, TX 76034

Tele Vue Optics, Inc. ..... (914) 735-4044
20-T Dexter Plaza
Pearl River, NY 10965

FILTERS

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

Meade Instruments Corp.....(714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626
Newport Glass Works. Ltd.....(714) 642-9980
2044-D Placentia Avenue
Costa Mesa, CA 92627

FOCUSERS

AstroSystems.....(303) 678-5339
P.O. Box 1183TM
Longmont, CO 80501
Kenneth Novak & Co.....(715) 532-5102
Box 69T
Ladysmith, WI 54848
Lewis Michaels Engineering .....(716) 425-3470
48 Delemere Blvd., P.O. Box 248
Fairport, NY 14450-0248

LENS BLANKS

Newport Glass Works. Ltd.....(714) 642-9980
2044-D Placentia Avenue
Costa Mesa, CA 92627

Edmund Scientific features telescope accessories for the avid astronomy enthusiast interested in building telescopes and accessories.

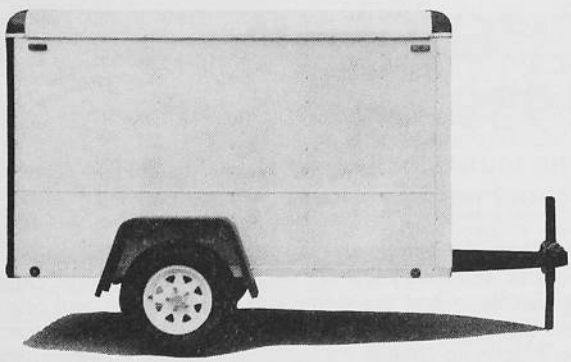
Write today for our FREE 172 page catalog containing over 7,000 hard-to-find science and optical products including optical instruments, optics, mirrors, fiber optics, lasers, magnets, magnifiers, microscopes, lab equipment, weather, binoculars, pumps and motors, measuring and test equipment, plus...

- EDMUND RKE® EYEPIECES
- KELLER AND ORTHOSCOPIC EYEPIECES
- PRECISION OPTICS
- IMAGE ERECTORS
- CAMERA ADAPTERS
- PARABOLIC MIRRORS
- BOOKS AND ATLASES FOR THE ASTRONOMER

Makers of the Edmund Astroscan® and Other Fine Telescopes

Edmund Scientific Co.
Dept. 10B1, N919 Edscorp Bldg., Barrington, NJ 08007

"With a Wells Cargo Behind . . . You Never Look Back"



WHY REPACK EVERYTHING...EVERYTIME YOU HEAD FOR DARK SKY?

One observer we read about packs chairs, cots, coffee pot and heater, too in his Wells Cargo. He's ready to roll. About the only thing left to load is his telescope. That kind of storage and transport means the family car is no longer a repeated load...unload proposition. The cost is less than you think. Call today, and find out.

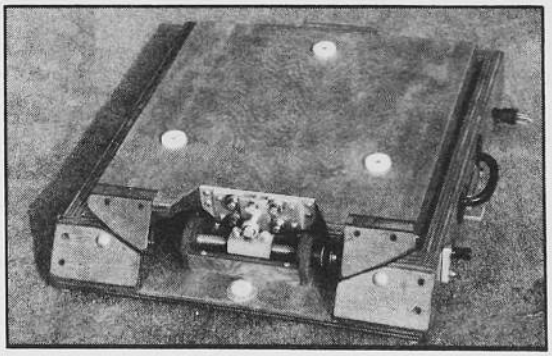
- Factory Service Facilities - GA, IN, TX, UT.
- US Wide Dealer & Service Network.
- Second-to-None 3 Yr. Warranty Coverage.
- Full Line Ball-Hitch Units 6' — 32' and Up.
- Full Line Fifth Wheel Units 20' — 40' and Up.

CATALOGS • PRICES • DEALERS
4 PLANT LOCATIONS
CALL 1-800-348-7553
TELL US YOU SAW IT IN TELESCOPE MAKING

WELLS CARGO SINCE 1954
P.O. BOX 728-960 ELKHART, IN 46515

EQUATORIAL PLATFORMS

FOR DOBSONIAN TELESCOPES OF ALL SIZES



THESE PLATFORMS ARE TRUE EQUATORIAL MOUNTS

By adding just a few inches to the height of your Dobsonian telescope, full MOTORIZED TRACKING CAPABILITY is attained. Wherever you point – using the smooth and stable Dobsonian movements – you are tracking, automatically and precisely. There is no field rotation – nor any need for a computer to perform complicated adjustments in altitude and azimuth.

An EQUATORIAL PLATFORM creates new observing opportunities:

- You will find yourself using higher powers more often – for a closer look and a darker sky background.
- Group viewing and star parties are enhanced. Everyone gets to enjoy the view, without constant image drift. Each object can be studied at length.
- Astrophotography beckons. Piggyback a camera on your telescope and shoot the Milky Way for up to an hour. Take high resolution photos of the moon and planets. And, with a Dual-Axis Platform, long exposure prime focus photography becomes possible.

For the latest fully illustrated brochure and price list, send $2.00 to:

EQUATORIAL PLATFORMS
11065 Peaceful Valley Rd.
Nevada City, CA 95959
(916) 265-3183 *(Evenings)*

Platform drive components available for telescope makers – ask for parts price list.

Enterprise Optics

Quality Optics Since 1979
For the Discriminating
Amateur and Professional
Astronomer

Newtonian and Cassegrain Optics
6″ to 24″

Over 25 Years Experience

1990 Complete Optics Catalog, Send $1.00 U.S.
$2.00 Canada or Foreign, in U.S. Currency.

Enterprise Optics
P.O. Box 413, Dept. A
Placentia, CA 92670 USA
(714) 524-7520

LENS KITS

Newport Glass Works. Ltd..... (714) 642-9980
2044-D Placentia Avenue
Costa Mesa, CA 92627

LENSES — OFF-THE-SHELF

D & G Optical ..... (717) 560-1519
6490 Lemon Street
East Petersburg, PA 17520

MACHINING SERVICES

Lewis-Michaels Engin. . ..... (716) 425-3470
48 Delemere Blvd., P.O. Box 248
Fairport, NY 14450-0248

B.D. Manufacturing..... (315) 754-6335
RD #2
Savannah, NY 13146

MIRROR BLANKS

Newport Glass Works. Ltd..... (714) 642-9980
2044-D Placentia Avenue
Costa Mesa, CA 92627

HIGH QUALITY ALUMINIZING

Enhanced Aluminum				Regular Aluminum			
4.25"	$36.00	12.5"	$106.25	4.25"	$13.80	12.5"	$ 40.75
6.00"	$51.00	14.5"	$205.00	6.00"	$19.50	14.5"	$ 82.00
8.00"	$68.00	16.0"	$228.00	8.00"	$26.00	16.0"	$ 92.00
10.00"	$85.00	17.5"	$250.00	10.00"	$32.50	17.5"	$100.75

$5.00 to strip old aluminum
Matching diagonals coated at no charge

All coatings guaranteed in writing
Our simple promise to you-
If the coating fails under normal use
we will recoat your mirrors at no charge.

Please send your mirrors now!!

Add return shipping and insurance

P.A.P. COATING SERVICES
1112 Chateau Ave.
Anaheim, CA 92802
(714) 778-2525

TELESCOPE MAKERS CHOICE SINCE 1939

One source for
all your needs

Adapters • Aluminizing • 12V Astronomers' Flashlights • Beeswax •Cases • Cleaning Supplies • Compounds: Grinding, Finishing and Polishing • Diagonals: Star and Sun • Dust Caps and Plugs • Drives • Edging Stones • Erectors • Eye: Patch and Guards • Eyepieces • Filters • Finders: Star, Polar Alignment, Illuminated and Brackets • Flat Black Paint • Focusers • Heads: Slow motion, Ball & Socket • Holders: Mirrors, Eyepiece lens, Filters, Multiple Eyepiece and Binocular • Inverters • Kits: Mirror Making and Testing • Lenses: Objective and Barlow • Mirrors: Finished, Blanks and Tools • Mounts: Equatorial, Camera, Triple Accessory • Pitch • Pitch-Lap Molds • Screws • Screens: Ronchi and Sun Projection • Setting Circles and Pointers • Slow Motion Controls • Templates • Tripods • Tube: Assemblies, eyepiece, Telescope and Mounting rings • Weights: Tube and Declination • Zone Testing Masks

OVER 500 ITEMS • 2 CATALOGS $3.00

OPTICA

OPTICA b/c COMPANY
Catalog Department
4100 MacArthur Blvd.
Oakland, CA 94619

LUMICON

HIGH PERFORMANCE TELESCOPE PARTS

LUMICON® SKY VECTOR™- *NEW!*

Computer-Controlled Digital Setting Circles, from $498

Incredibly Smart! thus Incredibly Easy!

- Digital right ascension readout to 1 minute of R.A.
- Digital decl. readout to 10 arc-min
- 2X higher resolution encoders
- Polar alignment **not required!**
- Motor drive **not required**
- Just sight two stars!
- Works for alt-azimuth **and** equatorial mounts

LUMICON Sky Vector™ (state scope) **$498**
Sky Vector™ Kit (you supply hardware) **$459**
Pair digital shaft encoders (for 2nd scope) **$149**

LUMICON 50mm, 80mm SUPER-FINDER™

Visual Astronomers perfer the LUMICON 80mm SUPER-FINDER™, since hundreds of deep-sky objects, including most Messier objects, are visible directly. SUPER-FINDERS also make nice small portable telescopes. 80mm aperture, F=300mm coated achromat. The deluxe SUPER-FINDER uses an 80mm, F=500mm air spaced achromat.

1¼" 50mm Finderscope **$59.50**, right-angle **$89.50**
1¼", straight-thru 80mm SUPER-FINDER **$169**
1¼" right-angle version, w/star diagonal **$195**
1¼" Deluxe right-angle Super-Finder **$279**
25mm Cross-hair 1¼" eyepiece (12X) **$29**
1¼" Star Diag. . . **$32**, 2" Star Diag., silver, . **$159**
1¼" Amici Prism diag. for correct left-right views **$69.50**

COMA CORRECTOR LENS

Coma 1 inch off-axis (17½" f/4.5)

Same Field with LUMICON coma corrector lens; note smaller, more numerous stars.

This computer-designed LUMICON 2" lens reduces coma and flattens the field for both viewing and photography. It threads into LUMICON 2" EASY-GUIDERS for effortless installation. This lens is optimized for f/4.5 and reduces aberrations for f/3.5 to f/5 Newtonians. Off-axis images are much smaller, making off-axis guiding far easier and yielding round pinpoint star images in photos. Since star images are sharp over a full 2¼" circle, you can use medium format cameras in addition to 35mm cameras. This zero power lens does not change image scale nor shift focus, and all lens surfaces are multi-coated for highest efficiency. Although designed for photography you may also use this lens to improve image quality in wide-field viewing with low power eyepieces.

LUMICON Coma Corrector/Field Flattener
2" lens **$285.00**
Extension tube for viewing **$26**
2" Easy-Guider™ (state camera) . . **$169.50**

LUMICON®
2111 Research Drive #5T Livermore CA 94550
For phone orders please call (415) 447-9570
LUMICON Products catalogue $2.
Foreign orders add $8 ($20 for HYPER-KITS)
California Residents add 6% tax.
Prices subject to change w/o notice.

NEW! ENCHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE

LUMICON 1.3" & 3.1" enhanced silver diagonal mirrors & 2" star diagonal.
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave.

1.32" **$29.95** 1.52" **$34.50** 1.83" **$39.50**
2.14" **$49.50** 2.60" **$65.00** 3.10" **$89.50**

ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.
1¼" (1.32" mirror) **$99.50**
2" (1.83" mirror)(see photo above) . . **$159.00**

OXYGEN-III FILTER

Helix Nebula, NGC 7293 in Aquarius. Bright and easy with Lumicon Oxygen-III Filter.

The ultimate in filter performance! The Lumicon Oxygen-III Filter has a contrast twice as high as the high performance Lumicon UHC Filter™. Use the Oxygen-III Filter for observing the very faintest planetary and diffuse emission nebulae. Also gives incredible views of bright nebulae (like M-27, M-17, etc.) from urban locations. Bandpass is 11nm, transmission is 90% for both O-III lines at 496nm and 501nm.

Filter Type	1¼"	48mm
Lumicon Oxygen-III	$99.50	$199.50
Lumicon UHC	$99.50	$199.50
Lumicon Deep-Sky	$79.50	$119.50
Set UHC and Oxygen-III	$190.00	$380.00

NOTE: The Oxygen-III Filter is not a substitute, but a compliment to the UHC Filter. **1 year guarantee:** You must see nebulae with the O-III filter that are **invisible** without a filter.

NEW ADJUSTABLE PIGGYBACK MOUNT

LUMICON has just designed a new adjustable piggyback mount ideal for all telescopes of 8-14" aperture. It has **both** vertical and sideways adjustment to allow optical alignment. It was designed to allow mounting of the LUMICON SUPER-FINDER on C-8, C-14, etc., but is ideal for any telephoto lenses or small telescopes.

Deluxe Piggyback Mount **$54.00**
(State Telescope Type)
LUMICON 12x80mm SUPER-FINDER $195.00

NEW! LOW PROFILE HELICAL FOCUSERS

LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a 6" telescope.
LUMICON now offers 3 different low-profile helical focusers. They stand only 1¼-1½" above the telescope tube. Use the 1¼" or 2" versions for viewing. Use the 2" non-rotating focuser for convenient photography with the LUMICON 2" EASY-GUIDER™.
Select your desired base-plate shape!
Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 21" OD, SUPER-FINDER base plate.
LUMICON 1¼" Helical Focuser **$49.50**
LUMICON 2" Helical Focuser **$59.50**
LUMICON Non-rotating Helical Focuser $89.50
3 handles (see photo) for non-rotat. focuser **$12.95**
2" Rack & pinion low profile focuser . . . **$129.00**
2"/1¼" adapter w/48mm filter threads . . . **$20.00**
2" LUMICON EASY-GUIDER **$169.50**

PROTECTIVE DUST COVERS

Protective plugs (left), vinyl dust covers.
Protect your valuable telescope optics, eyepieces and accessories with these black vinyl covers. Add $1 shipping. Deduct 10%, 2 or more sets.

1¼" O.D. plug, seals focuser	4/$2		
2" O.D. plug	2/$2	3½" O.D. plug	$1.50
1¼", 1⅜"	3/$2	7½"	$8
1½"	2/$2	9½", 10.4"*	$12
2"	2/$2	12½", 12⅞"*	$15
3½", 4½"	$5	16"*	$20
5½"	$6	19" (DS-16)	$35
*Fits Odyssey		21" (Odyssey 17½)	$35

MAKE YOUR OWN ASTROGRAPH

FILM HYPERSENSITIZATION KITS†

LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

†U.S. Patent 4,473,636

MAKE YOUR OWN HYPERED FILM

MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds **$295.00**

MODEL 600 HYPER-KIT (See Photo) Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates **$350.00**

MODEL 1200 HYPER-KIT is for 4X5" plates and film up to 5X7". Has 2 gas cylinders and includes temperature controller **$595.00**

Temperature controller for any HYPER-KIT **$65.00**

Electric Vacuum Pump **$319.00**

GUIDE OFF-AXIS FOR LOVELY ASTROPHOTOS

All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X easier guide-star selection, use 48mm filters, 360° camera rotation, large prisms of bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent #4,448,500

NEWTONIAN EASY-GUIDER™

Full aperture. Installs in secs. Specify 2" or 1¼".

NEWTONIAN EASY-GUIDER **$169.50**
3X Relay Diagonal (see photo) **$89.50**
Illuminated reticle eyepiece system . . **$99.50**
Guider for Hasselblad **$350,** Mamiya 645 **$199**

CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation —3X shorter exposures! **Superb rich field viewing, too!**
CASSEGRAIN EASY-GUIDER **$225.00**
Adapter for Hasselblad $185, Mamiya 645 **$98**

GIANT EASY-GUIDER™

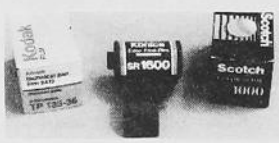
For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER **$395.00**
48mm DEEP-SKY Filter ordered with any EASY-GUIDER (SAVE $20) . . . . . **add $99.95**
Adapter for Hasselblad adapter **$195,** Mamiya 645, **$119**

WHAT DO YOU NEED?

1. Illuminated reticle eyepiece **$99.50**
Lumicon 12mm eyepiece system has adjustable L.E.D. illumination, dual crosslines, battery pack.
2. Cable release for long exposures . . **$9.95**

3. **LUMICON Quartz Drive Corrector . $219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.
Declination motor (state telescope) . . $99
NEW Deluxe Digital Qtz. Drive Correc. **$298**



HYPERSENSITIZED FILM
LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	Exposures	Price
2415, Ultra-fine B&W, red sens.	36	$10.95
SR3200, fastest of all, color neg	24	$13.95
Konica SR400, fine gr. color neg	12	$10.95
3M 1000, fastest slide film	20	$12.95
Fujichrome RD100, fine gr. slide	24	$12.95
5072, color slides from negs	36	$6.95
D-19 B&W Developer	1 gal.	$6.95

MIRROR COATING

Evaporated Metal Films ..... (607) 272-3320
701 Spencer Road
Ithaca, NY 14850

MIRRORS — CUSTOM MADE

Enterprise Optics ..... (714) 524-7520
P.O. Box 413
Placentia, CA 92670

Galaxy Optics ..... (719) 395-8242
P.O. Box 2045
Buena Vista, CO 81211

Earl Watts Optics ..... (415) 786-2967
26638 Jamaica Lane
Hayward, CA 94545

MIRRORS — DIAGONALS

Enterprise Optics ..... (714) 524-7520
P.O. Box 413
Placentia, CA 92670

E & W Optical Inc. ..... (612) 331-1187
2420 E. Hennepin Ave.
Minneapolis, MN 55413

Galaxy Optics ..... (719) 395-8242
P.O. Box 2045
Buena Vista, CO 81211

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

Meade Instruments Corp ..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

MIRRORS — FLATS

E & W Optical Inc. ..... (612) 331-1187
2420 E. Hennepin Ave.
Minneapolis, MN 55413

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

MIRROR KITS

Newport Glass Works. Ltd ..... (714) 642-9980
2044-D Placentia Avenue
Costa Mesa, CA 92627

LENSES, ACHROMAT LENSES, FILTERS & MIRROR BLANKS

★ ★ **ATTENTION: OEM's, CLUBS & DO-IT YOURSELF FABRICATORS** ★ ★

★ ★ ★ **BUY DIRECT** ★ ★ ★

Stock & Custom unfinished (not polished) fabricated/molded mirror blanks, diagonals, prisms & lenses made from Pyrex,® optical glasses, colored filter glasses, fused silica, quartz and other low expansion ceramic materials.

STOCK: NEWPORT GLASS WORKS, LTD. molds and maintains an inventory of Pyrex® stock mirror blanks (1:6 ratio) in sizes from 1" (25.4mm) to 26" (660mm) in diameter. Many of these blanks come with f/curves molded on one face to make your fabrication effort more efficient. Newport also maintains an inventory of secondary mirror blanks and diagonals (minor axis ranging in size from ½" (12.7mm) to 6⅜" (162mm)). All blanks are fine annealed. Precision annealed blanks can be supplied on request.

LIGHTWEIGHT: NEWPORT GLASS WORKS, LTD. produces "lightweight" mirror blanks (e.g., conicals, ribbed, cellular, ultra-thin) of various sizes and design up to 40" (1016mm) in diameter. Many of these blanks have been fabricated to the customers' specifications.

OPTICAL: NEWPORT GLASS WORKS, LTD. also molds optical glass materials (crowns, flints, etc.) to meet your requirements for lenses, achromats, prisms, windows and corrector plates.

LOW EXPANSION: NEWPORT GLASS WORKS, LTD. also can meet your requirements for blanks made from quartz, fused silica, Vycor® and low expansion ceramics (e.g., Zerodur®).

FILTERS: NEWPORT GLASS WORKS, LTD. maintains one of the largest inventories (over a 100 different material types) of colored filter glass blanks in the United States.

CUSTOM: NEWPORT GLASS WORKS, LTD. has the capabilities of meeting the custom designs of the fabricator. In many instances Newport can select existing tooling from its large inventory of fabrication tools to fulfill the expectations of the fabricator without a tooling charge.

EXPERIENCE: NEWPORT GLASS WORKS, LTD.'s staff has over 40 years of experience in the fabrication of lenses and mirror blanks for commercial, industrial, military and amateur fabricators. To meet your delivery requirements, Newport maintains a large inventory (tons) of raw material.

Write, call or fax for free catalog.

NEWPORT GLASS WORKS, LTD.
2044-D PLACENTIA AVENUE
COSTA MESA, CA 92627

(TEL): 714-642-9980 (FAX): 714-642-4832 (TELEX): 9102408375

Collimation Tools

"Because Collimation is the number one killer of telescopes world wide" —Walter Scott Houston

"I recommend these tools to anyone who wants top notch performance from a Newtonian reflector" —Richard Berry

Sight Tube ....(Basic tool for Newtonians) $29.50
Cheshire .....(For Newtonian primary and Refractors) 38.00
Autocollimator .(For critical alignment of Newtonians) 31.50
Set of all three..(set includes instruction booklet) 95.00

Ultra Low Focusers

Super smooth 2" Rack and Pinion Visual Model uses Teflon bearings and a brass rack. Critical focusing is fast and easy, even with the heaviest eyepieces. Total height is only 1.6", with 1.6" travel. Precision machined from solid aluminum and black anodized.

Complete with precision 1 1/4" adapter ...$125.00
Photographic model, 2 1/2" high.....$159.50

Tectron Telescopes

(813) 758-9890 • Made in the USA
2111 Whitfield Park Avenue
Sarasota, Florida 34243

Phone orders 7:00 AM to 3:30 PM EST M-F
Visa & MasterCard accepted
UPS shipping charges in US $4.50

Palomar Optical Supply..... (714) 678-5393
P.O. Box 1310
Wildomar, CA 92395

MIRRORS — OFF-THE-SHELF

Meade Instruments Corp..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

MOUNTINGS — COMPLETE

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

Great Lakes Instruments..... (517) 339-1151
1971 Haslett Rd., Box 610
Haslett, MI 48840-0610

Cambridge University Press

SUPERNOVA SEARCH CHARTS AND HANDBOOK
Gregg D. Thompson *and* ***James T. Bryan, Jr.***
This unique atlas contains 236 charts of more than 300 of the brightest galaxies, each specifically prepared to facilitate the discovery of supernovae. The comparison of these charts with the field seen in a telescope enables any extra-galactic supernova to be spotted immediately.
1989 96 pp. 236 charts 26721-8 Boxed Set $100.00

OBSERVING HANDBOOK AND CATALOGUE OF DEEP-SKY OBJECTS
Christian B. Luginbuhl *and* ***Brian A. Skiff***
The most detailed and comprehensive guide to deep-sky observing available in one volume, this product of meticulous research describes nearly 2,050 galaxies, nebulae and star clusters.
1990 352 pp. 25665-8 Hardcover $49.50

At bookstores or from
CAMBRIDGE UNIVERSITY PRESS
40 West 20th Street, New York, NY 10011. Call toll-free 800-872-7423 outside NY State.800-227-0247, NY State only.
MasterCard/VISA accepted. Prices subject to change.

IT'S NOT A STORE . . .

IT'S AN ADVENTURE!

Discover the hidden treasures at the Scope City Surplus Store. Featuring new, used, antique and one-of-a-kind astronomical equipment, including parts, components, hard-to-find items, accessories, objective lenses, cosmetically defective items, re-packs and floor models. It's a "fixers paradise," offering a repair and collimation service, consignment and trade-ins.

HUGE SELECTION
SAVE UP TO 80%

VISIT THE WORLD'S LARGEST AND MOST COMPLETE TELESCOPE & BINOCULAR DISCOUNT CENTERS

SCOPE CITY SURPLUS STORE

MAIN OFFICE
679 Easy St.
Simi Valley, CA, 93065
(805) 522-6646

MAIL ORDER
P.O. Box 440
Simi Valley, CA 93065
Info & ordering in CA
(805) 522-6701
Nat'l (800) 235-3344
Send for a FREE discount price list. $5.00 for catalog package.

SAN DIEGO, CA
4766 Clairemont Mesa Blvd.
(805 Fwy. to Clairemont Mesa Blvd., exit west)
(619) 277-6686

COSTA MESA, CA
3033 S. Bristol
(405 Fwy. to Bristol exit, 2 blks. south)
(714) 957-6900

TORRANCE, CA
3132 Pacific Coast Hwy. (405 Fwy. to Crenshaw exit south, west on Pac. Coast Hwy. 3 blks.)
(213) 326-3251

SIMI VALLEY, CA
679 Easy St.
(118 Fwy. to First St. exit, south ½ mile, right on Easy St. 2 blks.)
(805) 522-6646

SHERMAN OAKS, CA
14324 Ventura Blvd.
(101 Fwy. to Van Nuys, exit south, left on Ventura Blvd., go 1 blk. to Oakridge Plaza - corner of Beverly Glen)
(818) 789-5805

LAS VEGAS, NV
2216 Paradise Rd.
(Corner of Paradise Rd. and Sahara Ave., across from Sahara hotel.)
(702) 733-9288

SURPLUS STORE
679 Easy St.
Simi Valley, CA 93065
(118 Fwy. to First St. exit, south ½ mile, right on Easy St. 2 blks.)
(805) 522-6646

EMPLOYMENT OPPORTUNITIES AVAILABLE
WRITE MAIN OFFICE

TELESCOPE ACCESSORIES

Celestron International ..... (800) 421-1526
(213) 328-9560
2835 Columbia St.
Torrance, CA 90503

Edmund Scientific Co. ..... (609) 573-6266
N19B1-N919 Edscorp Bldg.
Barrington, NJ 08007

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

Meade Instruments Corp..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

Parks Optical ..... (805) 522-6722
270 Easy St.
Simi Valley, CA 93065

Scope City ..... (800) 235-3344
In California (805) 522-6701
P.O. Box 440, Simi Valley, CA 93065

Tectron Telescopes ..... (813) 758-9890
2111 Whitfield Park Ave.
Sarasota, FL 34243

TELESCOPE PARTS

Lewis-Michaels Engineering ..... (716) 425-3470
48 Delemere Blvd., P.O. Box 248
Fairport, NY 14450-0248

Meade Instruments Corp ..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

Kenneth Novak & Co..... (715) 532-5102
Box 69T, Ladysmith, WI 54848

Parks Optical ..... (805) 522-6722
270 Easy St.
Simi Valley, CA 93065

Tele Vue Optics, Inc. ..... (914) 735-4044
20-T Dexter Plaza
Pearl River, NY 10965

Earl Watts Optics ..... (415) 786-2967
26638 Jamaica Lane
Hayward, CA 94545

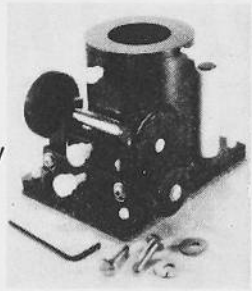
TELESCOPE TUBES

Lewis-Michaels Engin. ..... (716) 425-3470
48 Delemere Blvd., P.O. Box 248
Fairport, NY 14450-0248

UPGRADE YOUR TELESCOPE

Modified Crayford Design

- 2" focuser with 1¼" adapter included
- Low profile
- Corrosion resistant materials used throughout
- Two-speed focusing
- Unparalled smoothness and accuracy
- Fits any size tube (please state thickness)
- Three year warranty. 30 day money back guarantee. $129.00, plus $3.50 postage/handling in U.S.



LAMINATED TO LAST INTO THE NEXT CENTURY

SKY ATLAS 2000.0 by Wil Tirion

Field or Desk Edition	$59.00
Deluxe/color Edition	$79.00

Newly improved wiro binding with sturdy plastic covers and erasable marking pencil, plus $3.50 postage/handling in continental U.S.

AstroSystems, Inc.
P.O. Box 1183 TM-41
Longmont, CO 80501
(303) 678-5339
Call Toll-Free 800-477-5621

MC/VISA
CO residents add 3% tax

Send for free brochure
Made in U.S.A.

OBJECTIVE LENSES

Air-spaced doublets mounted in fully adjustable aluminum cells.

5" f/15, coated, ppd.	$675.00
6" f/15, coated, ppd.	$895.00
8" f/15, uncoated, ppd.	$2395.00

The 8" lens is very superb. The resolution, definition and contrast is way beyond our expectations.
A. George, Puyallup, WA

Thanks for your timely completion of the task and your businesslike commitment to your optical endeavors.
R. Morgan, Ventura, CA

The 6" lens is giving excellent results. The color correction is superior to a nearby 6" lens of the same focal length but of different manufacture.
S. Allison, Tacoma, WA

You have satisfied a lifelong dream, an observatory size refractor, at a price I could afford, in less than two months. Wow!
G. Zeller, Baltimore, MD

30 day money-back guarantee. Other sizes, different focal lengths, and complete tube assemblies are available. Send $1.00 for catalog.

D & G OPTICAL
6490 Lemon Street
East Petersburg, PA 17520
Phone: (717) 560-1519

Meade Instruments Corp ..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

TELESCOPES, COMPLETE

Celestron International ..... (800) 421-1526
(213) 328-9560
2835 Columbia St., Torrance, CA 90503

Lumicon ..... (415) 447-9570
2111 Research Dr., Suite 5
Livermore, CA 94550

Meade Instruments Corp ..... (714) 556-2291
1675 Toronto Way
Costa Mesa, CA 92626

Parks Optical ..... (805) 522-6722
270 Easy St.
Simi Valley, CA 93065

AT LAST, A LOW COST, EQUATORIAL MOUNT REFLECTOR

Our EQUATORIALLY mounted Newtonian reflectors set up and take down in SECONDS without tools or fasteners, much like a Dobsonian mounted scope. Unlike the Dobsonians, however, our mounts can be easily fitted with a driving unit for convenient tracking in right ascension. The Declination Safety Trunnion (patents pending) makes Dobsonian-like set up and take down possible. The 6" and 8" scopes are very light weight and portable. Your choice of focal ratio. Build-it-yourself kits are complete and easy to assemble, with complete and thorough instructions. Complete kits (without optics):

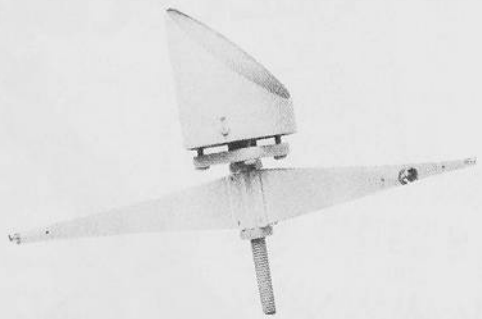
- 6"... $259
- 8"... $339
- 10"... $569
- 13.1"... $589
- Plans and patterns to "scratchbuild" mount... $50.00

We can also provide kits complete with optics, or build your instrument for you. Send for free information.

GREAT LAKES INSTRUMENTS
1971 Haslett Rd., Box 610 • Haslett, MI 48840-0610
(517) 339-1151

VISA Designs licensed from Great Plains Instruments, Enid, Oklahoma MasterCard

LARGEST SELECTION OF QUALITY TELESCOPE COMPONENTS



Our secondary mirror holders are of an exclusive design for very low optical strain. Fully adjustable for collimation, axial, and rotational adjustments without springs for positive locking and compact size. Lightweight aluminum construction with continuous retaining rim — no thick molded plastic or tabs. Low overhang for stability. Adjustable for variations in mirror thickness.

Spiders feature very thin stainless-steel vanes tapered to a proper width at the lightweight aluminum center body. Each spider is individually designed to fit tube size so vanes are wider on larger spiders. We do not simply put longer vanes on a small spider to make a large spider. The very low mass of the unit combined with the tapered vanes gives exceptional stability even with large diagonals used in rich-field and large-aperture telescopes. Curved spiders to eliminate diffraction spikes also available.

LARGEST SELECTION OF QUALITY TELESCOPE COMPONENTS AVAILABLE FROM STOCK

31 Newtonian mirror mounts, 4¼" to 20"
12 Cassegrain mirror mounts, 4¼" to 14¼"
33 Spiders, for tubing 5" to 24"
22 Diagonal holders, 1¼" to 4½" minor axis
6 Cassegrain secondary holders, 2.27" to 4.00"
11 Focusers, regular and SuperShort
9 Focuser accessories
8 Star diagonals, .965," 1¼", and 2"
6 Ring Mounts for guide telescopes

Plus tube counterweights, mirrors, and a booklet on Cassegrain telescopes

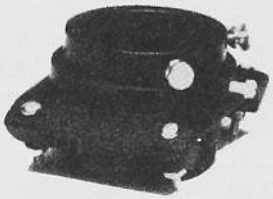
Newtonian Notes

Designing, assembling, and collimating a high performance telescope from commercial parts.

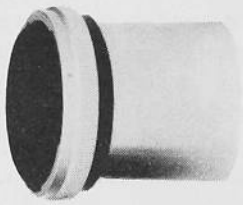
"...truly one of the most excellent publications on..the Newtonian reflector."

— M.S., New Mexico

Rich field telescopes covered in detail. 60 pages. **$6.95 ppd.** Add $1.50 for First Class Mail.



SuperShort 2" focuser with wide cast aluminum light-shielded base, dual locking screws, and silky-smooth fine focusing with exceptional stability. Full line of adaptors and travel extenders available. Newtonian Model SS focuser. **—$48.95**



2" FIRST FOCUS CAMERA ADAPTER
for low vignetting & widest field. Available to fit most 35-mm cameras (specify brand). Most models — **$22.95**

OUR 22nd YEAR! Write or call weekday afternoons for free 1990-1991 24-page catalog. ($1.00 postage outside United States.)

Kenneth Novak & Co., Box 69T, Ladysmith, WI 54848 • Tel. (715) 532-5102

GALAXY OPTICS

MANUFACTURERS OF QUALITY NEWTONIAN TELESCOPE OPTICS

QUALITY WORKMANSHIP - GUARANTEED - REFERENCES AVAILABLE

All ***GALAXY OPTICS ULTIMATE IMAGE™ MIRRORS*** are thoroughly tested throughout each stage of completion and are totally hand-figured and null tested to assure you of a professional quality paraboloidal optic.

GALAXY'S ULTIMATE IMAGE™ full thickness (1:6) and lightweight mirrors (2.00") are made from Precision annealed *molded* Pyrex mirror blanks and are available with a choice of two outstanding reflective coatings.

COATING #1: 88% Reflectivity - Aluminized and quartz overcoated
COATING #2: 96% Reflectivity - Broadband multilayer dielectric coating over aluminum

FULL THICKNESS 1:6 OPTICS

MIRROR	COATING #1	COATING #2
10"	$ 475	$ 525
12.5"	625	700
16.0"	1800	2050
18.0"	2400	
20.0"	3500	

LIGHTWEIGHT 2.00" THICKNESS OPTICS

MIRROR	COATING #1	COATING #2
14.5"	$ 950	1150
16.0"	1200	1450
18.0"	1400	
20.0"	1750	
22.0"	3150	
25.0"	4950	

GALAXY'S ultra-lightweight mirrors (1.6") are made from fine annealed Pyrex mirror blanks and are manufactured to the same specifications as our 1:6 mirrors.

ULTRA-LIGHTWEIGHT 1.6" OPTICS

MIRROR	COATING #1	COATING #2
14.5"	$ 825	$1025
16.0"	1050	1300
18.0"	1200	
20.0"	1500	
22.0"	2550	

ULTIMATE IMAGE™ ELLIPTICAL DIAGONAL FLATS
LASER QUALITY - TRUE 1/10 WAVE FLATS
1/10 WAVE, 20/10 SURFACE QUALITY - GUARANTEED

MINOR AXIS	COATING #1	COATING #2
2.1"	$ 75	$100
2.6"	75	100
3.1"	95	120
3.5"	265	300
4.0"	285	325
5.0"	425	475

All mirrors are available in many popular focal ratios. Full thickness (1:6) and ultra-lightweight Zerodur® Optics available. Mirror refiguring services, write for quotation. For a complete product catalog mail $1.00 to:

GALAXY OPTICS
P.O. BOX 2045 • BUENA VISTA, COLORADO 81211 • (719) 395-8242

Scope City ..... (800) 235-3344
In California (805) 522-6701
P.O. Box 440
Simi Valley, CA 93065

Sky Designs ..... (817) 656-4326
4100 Felps Dr., Bldg. C
Colleyville, TX 76034

Tele Vue Optics, Inc. ..... (914) 735-4044
20-T Dexter Plaza
Pearl River, NY 10965

Earl Watts Optics ..... (415) 786-2967
26638 Jamaica Lane
Hayward, CA 94545

Advertising Information:
Greg Swan
(800) 558-1544 Ext. 628

BUILD YOUR OWN TELESCOPE

By TELESCOPE MAKING Editor Richard Berry

Build your own telescope with less expense, time and effort than you ever imagined! Written by TELESCOPE MAKING's Richard Berry, **BUILD YOUR OWN TELESCOPE** features complete plans for five telescopes, along with easy-to-follow, step-by-step instructions and photos. For these projects, you'll need no special tools, and **BUILD YOUR OWN TELESCOPE** will tell you where to obtain all the components needed!

BUILD YOUR OWN TELESCOPE includes introductory chapters on how telescopes work, and discusses telescope optics, mountings, and accessories. And for a real challenging project, there are chapters on grinding, polishing, and testing telescope mirrors!

"...everything was so explanatory. Your detail in the step-by-step mode was ingenious! You left no questions to be asked...I enjoyed the task as much as I've enjoyed the goal...It (the telescope) has turned out beyond my most elaborate expectations."

• Dennis R. Culver, Huntsville, AL
Von Braun Astronomical Society Member

Kalmbach Publishing Co., P.O. Box 1612, Waukesha, WI 53187-1612 **0132**

YES! Please send me _____ copies of BUILD YOUR OWN TELESCOPE! Price per copy is $24.95/#30124.

❑ My check/money order is enclosed.

Charge to: ❑ American Express ❑ MASTERCARD ❑ VISA

Name _____

Street _____

City, State, Zip _____

Card Number _____ Exp. Date _____

Signature _____

Send this coupon or a copy to TELESCOPE MAKING Dept. 0132, P.O. Box 1612, Waukesha, WI 53187-1612. Include for postage and handling: U.S. $1.50; Canada and foreign add 15%. Wisconsin residents add 5% sales tax.

Paracorr™ Eats Coma

At Last, a *Universal* Coma Corrector for Parabolic Mirrors

There's no question large aperture reflectors like John Vogt's excellent 30" f/3.8 produce deep sky views rivaling those I've seen in major observatories. But his scope, like yours, is limited in field sharpness. The main offender is coma, an aberration which makes stars look like blurry comets. Visually and photographically, the faster the scope the worse the effect.

If we compensate for coma before starlight reaches the eyepiece, then the best eyepieces will be used to fullest advantage, and a sharp full frame 35mm photograph is possible. In sum, my design goals were:

1. maximum reduction in coma and field curvature without compromising spherical aberration and color correction

2. major sharpness improvement for all popular focal ratios

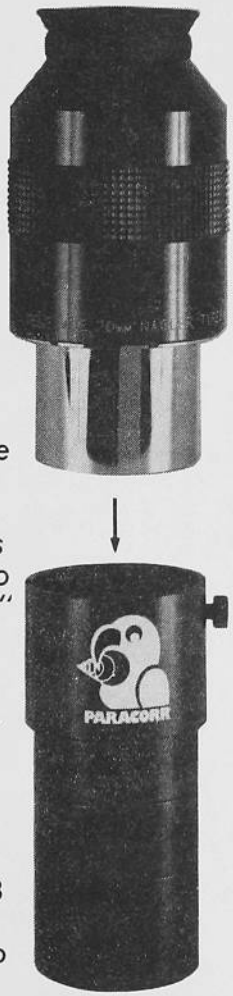
3. equally effective visually or for 35mm film

4. as convenient to use as a Barlow lens

I hope you agree that Paracorr, the coma eater, is the missing link necessary to fully enjoy your "DobNewt."

—Al Nagler

PARACORR™



The Formula For Increasing Sharp Field

A perfectly made 13" f/4.5 parabola has only about .1° diffraction-limited field. Now add Paracorr plus a Nagler eyepiece to your f/3.5–f/8 parabola and tremendously increase your sharp field. Extract all the performance the atmosphere and your mirror quality will allow. Since Paracorr tightens and intensifies star images, enjoy resolving globular clusters as they drift right to the edge of your field of view. No more finding the "sweet spot" of focus. The entire field is your "sweet spot"!

Astrophotography

Rival a Schmidt Camera? Mount your 35mm SLR to Paracorr, and the quality of full frame photos will be spectacular since star image sizes are designed to be less than .001 inch over the field for an f/4.5 mirror.

Easy To Use

Paracorr drops in like a Barlow lens. With only a slight 1.15x magnifying factor, an f/4.5 telescope becomes an f/5.17. While optimized for Tele Vue eyepieces, other makes can be used. Of course the better the eyepiece, the better the results. The 1¼" Paracorr is parfocal with most Tele Vue eyepieces. The 2" Paracorr requires about ½" in-travel from your current focus location. Can't be simpler for any scope, any eyepiece, and any 35mm SLR camera.

Paracorr — The Missing Link

An optical chain is as good as its weakest link. With the development of 82° Nagler eyepieces, Tele Vue offers the largest, flattest and best corrected visual fields in the industry. Combine the Nagler revolution, Dobsonian revolution and Paracorr for the ideal mating for flat-field and sharpness, visually and photographically. Try Paracorr on your "DobNewt." We think you'll agree that the revolution is complete.

A) parfocal 2"-1¼" adapter
B) 2" eyepiece holder
C) lens assembly threaded for T-rings

Paracorr — More stars, sharper stars, more time to observe. Send $3 for full line literature package.

Tele Vue™

20 Dexter Plaza, Pearl River, NY 10965
(914) 735-4044

Telescope Making Subscriptions and Renewals

❒ $12 for four issues ($14 foreign) ❒ New Subscription ❒ New Address
❒ $21 for eight issues ($25 foreign) ❒ Renewal
❒ Begin my subscription with ❒ this issue; ❒ the next issue.

Name _____

Address _____

City _____

State, Zip _____

Payment must accompany order.
Foreign subscribers must remit in U. S. funds.

When to renew: Look at your mailing label.
This will be your last issue.

700000165500 TMK (TM40) SC
RICHARD BERRY
21027 CROSSROADS CIRCLE
WAUKESHA WI 53186

TELESCOPE MAKING, Circulation Dept., P.O. Box 1612, Waukesha, WI 53187

TM BACK ISSUES AND REPRINTS

At present, most back issues of TELESCOPE MAKING are still available. Order now while quantities last. Remember the information found in TELESCOPE MAKING ***does not go out of date!***

See TM#20, pages 30 through 34, for our "Index to Back Issues," listing issues #1 through #20, or write to the address below for an updated index.

❒ **Please send me the TM Back Issues I've circled below.**

All back issues: $4.00 each. Or, order 25 or more back issues for only $3.00 each – a savings of 25%!

#5	#6	#7	#8	#10	#12	#14
#15	#16	#18	#19	#20	#21	#22
#23	#24	#25	#26	#27	#28	#29
#31	#32	#33	#34	#35	#36	#37
#38	#39	#40				

"How to Build Your Own Observatory" contains ideas that will help you build 17 great backyard observatories from a simple shelter from streetlights to a gleaming garage-top dome. Reprinted articles from TM, 80 pages, paperback, #18004.

❒ **Please send _____ copy(ies) of "How To Build Your Own Observatory" at $7.95 each, #18004.**

"Build Your Own Telescope" shows you how to make your own telescope at far less cost and with less time and effort than you ever imagined. By TM's editor, Richard Berry, it features complete plans for 5 telescopes, along with easy-to-follow, step-by-step instructions and photos. 276 pages, hardcover, #30124.

❒ **Please send _____ copy(ies) of "Build Your Own Telescope" at $24.95 each, #30124.**

Include for postage and handling: U. S. $1.50; Canadian and foreign add 15% (minimum $3). Wisconsin residents add 5% sales tax.

Total amount enclosed: $ _____

Name _____

Address _____

City _____

State, Zip _____

TM0094

If you don't wish to damage this copy of your magazine, just send us a photocopy or reasonable facsimile of this order form.

Please allow four to six weeks for delivery of your order. Payment must accompany order. Foreign orders please remit in U. S. funds; overseas orders are sent by surface mail.

TELESCOPE MAKING, Order Department, P.O. Box 1612, Waukesha, WI 53187